RAPID NONDESTRUCTIVE TESTING OF HEAT-TREATMENT QUALITY OF 2014 ALUMINIUM ALLOY[①]

Fan Jingyun, Wan Jing, He Yunbin and Wan Guoqing
Institute of Materials Science And Engineering,
Harbin University of Science and Technology, Harbin 150080, P. R. China

ABSTRACT Since there is a single-valued reverse "C" shape relation between the displayed values of low frequency WJF-38 type micro-computer-based automatic metal material separator and the hardness of 2014 aluminium alloy after solid solution treatments at different temperatures and natural aging, moreover, the parts without sufficient solid solution, the over-burnt parts and the hardening crack parts respectively appear at the top and bottom of the reverse "C" shape relationship curve, the hardness of the 2014 aluminium alloy can be quantitatively determined by the WJF-38 instrument. Its Brinell hardness, Rockwell hardness and Vickers hardness values can be directly displayed. The parts without sufficient solid solution, the over-burnt parts and the hardening cracked parts can also be accurately separated by using the WJF-38 instrument. Furthermore, there is also a reverse "C" shape relation between the hardness of 2014 aluminium alloy after artificial aging treatment and the displayed value of the WJF-38 instrument. The precision of the hardness tested by the WJF-38 instrument is about HRB ±1.3, and the separating speed can reach 1 500 parts per hour.

Key words aluminium alloy heat-treatment quality nondestructive testing

1 INTRODUCTION

Since the paper "Rapid, Nondestructive And Quantitative Testing of Hardness of Aluminium alloys" was published[1], many readers have been very concerning about the rapid nondestructive testing of aluminium alloy's heat-treatment qualities such as solid solution treatment degree, overburning, hardening cracks and hardness. So we particularly carry on the research of testing the quality of the 2014 aluminium alloy (which is liable to overburn) after solid solution treatment plus natural aging and artificial aging treatment. The results show that we can use the WJF-38 type micro-computer-based automatic separator[2,3] to rapidly remove the parts without sufficient solid solution, the over-burnt parts, the quenching cracked parts, the underaged and over-aged parts. It can also be used to quantitatively test the hardness after solid solution treatment and aging treatment. Moreover, it can be used to study the heat treatments of the aluminium alloys.

2 PRINCIPLE

The basic principle of using WJF-38 type instrument to test aluminium alloys's properties such as hardness has already been described in Ref.[1]. The instrument is successfully developed by means of differential mode. It is based on the fact that the output voltage of the tested part is in proportion to its electrical conductivity, that is, property indexes such as composition, hardness and stress. Two solenoid probes (also called crossing-mode probe) or a pen-shaped probe (also called placing-mode probe) is adopted for the instrument. The tested part is magnetized by a certain frequency ranging from 1 Hz to 1 500 Hz and the induced voltage signal is obtained. After the signals processing system and the single-chip-processor system have processed the signal, the part's composition, hardness and heat-treatment defects such as overburnt and

① Received Jul. 23, 1998; accepted Sep. 5, 1998

hardening cracks will be directly displayed on a four-digit display. If it is an unqualified part, the instrument can give an alarm by light and sound.

3 PREPARATION OF TEST PARTS AND EXPERIMENTAL METHOD

3.1 Preparation of test parts of 2014 aluminium alloy

Choose the as-delivered 2014 aluminium alloy rods with diameter of 10 mm and unprocessed surface, then cut them all into 80 mm length, that is, the test parts are d10 mm × 80 mm in dimension.

(1) Their solid solution temperatures are respectively 460, 480, 490, 500, 505, 510, 515, 520 and 530 ℃. Their holding time is all 45 min. Then they are water hardened at indoor temperature, and after that they undergo natural aging.

(2) They accept solid solution treatment at 495 ℃, then accept water hardening at indoor temperature after 60 min heat preservation, at last, they accept artificial aging treatment at 175 ℃. The aging heat preservation times are respectively 0.5, 1.0, 2.0, 3.0, 4.0, 4.5, 5.5, 6.5, 7.0 and 7.5 h.

3.2 Experimental method and equipment

Hardening heating and artificial aging are all carried out in the muffle furnace.

Test the hardness HRB values of the heat-treatment test parts mentioned above by HR150 type scleroscope. Observe the microscopic structure and defects such as hardening cracks of the heat-treated parts mentioned above by optical microscope. Test the heat-treatment quality such as hardness, over-aging, over-burning and hardening cracks of the heat-treated parts by WJF-38 instrument's value-displaying method and "Y1 method" for hardness testing.

4 RESULTS AND DISCUSSION

4.1 Relationship between solid solution temperatures and WJF-38 instrument's displayed values of 2014 aluminium alloy

The relationship between solid solution temperatures and WJF-38 instrument's displayed values of 2014 aluminium alloy is shown in Fig. 1. It is thus evident that the WJF-38 instrument's displayed values of 2014 aluminim alloy monotonously decrease with increasing solid solution temperature. The reason is that the increase of solid solution temperature increases the supersaturation degree of the 2014 aluminium alloy, meanwhile the density of vacant positions is also large, that is, 2014 aluminium alloy is in the double supersaturated state, both factors cause the reduction of electrical conductivity[4,5]. So the WJF-38 instrument's displayed values in proportion with electrical conductivity inevitably drop monotonously with increasing solid solution temperature.

The reason of the formation of the curve shown in Fig. 1 can also be explained by strengthening phase's dissolving condition dur-

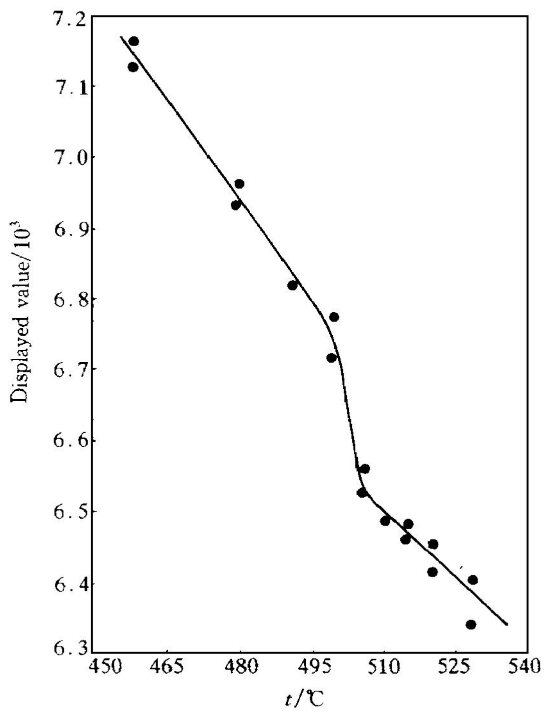

Fig.1 Relationship between solid solution temperature and displayed value of 2014 aluminium alloy on WJF-38 instrument (natural aging)

ing 2014 aluminum alloy's solid solution treatment. The major phases that have strengthening functions in 2014 aluminum alloy's aging are Mg_2Si, $CuAl_2$, Al_2CuMg and $Cu_4Mg_5Si_4Al_4$ phases. The check of metallography of the test parts undergoing solid solution treatments at different temperatures shows that when they are heated between 460 ℃ and 490 ℃, although the above-mentioned chemical compounds have dissovled, it is not obvious. When heated at 500 ℃, except for $CuAl_2$, the other phases have all remarkably dissolved. So the test parts' electrical conductivity drops linearly. Till the parts are heated between 505 ℃ and 510 ℃, the solid solution phenomenon is more notable, at this time the electrical conductivity almost drops vertically. When heated at 512 ℃, $CuAl_2$ phase begins to dissolve obviously, and the solid solution condition is growing better with increasing temperature. The electrical conductivity still drops linearly, but the dropping amplitude is subsiding. Known from Fig.1, we should choose 505 ℃ or so as solid solution temperature for 2014 aluminum alloy, because at this time the WJF-38 instrument's displayed value drops vertically.

4.2 Relationship between hardness and solid solution temperature of 2014 aluminium alloy

The relationship between hardness and solid solution temperature of 2014 aluminium alloy is shown in Fig.2 (after natural aging). It is thus clear that 2014 aluminium alloy's hardness increases with increasing solid solution temperature, and reaches the peak value at about 515 ℃. After the temperature exceeds 515 ℃, instead, the hardness decreases with increasing solid solution temperature.

As we have mentioned before, with increasing solid solution temperature, the supersaturation degree of 2014 aluminium alloy increases, the density of vacant positions is large, and the vacant position density kept at ambient temperature after solid solution is also large, thus the strengthening effect caused by aging is strong[7,8]. So with increasing solid solution temperature, the hardness increases and reaches the peak value at 515 ℃. By metallographic check, it is known that overburning appears in the test parts treated at 520 ℃ and 530 ℃, moreover, the hardening cracks appear in the test parts treated at 530 ℃. These factors result in the decline of mechanical properties such as hardness.

As shown in Fig.2, it's hard to judge the overburning defect by testing Rockwell hardness, it's also hard to discriminate the parts with insuffcient solid solution and serious overburning. Moreover, testing overburning by metallographic method can be only sample testing, and still it is destructive testing.

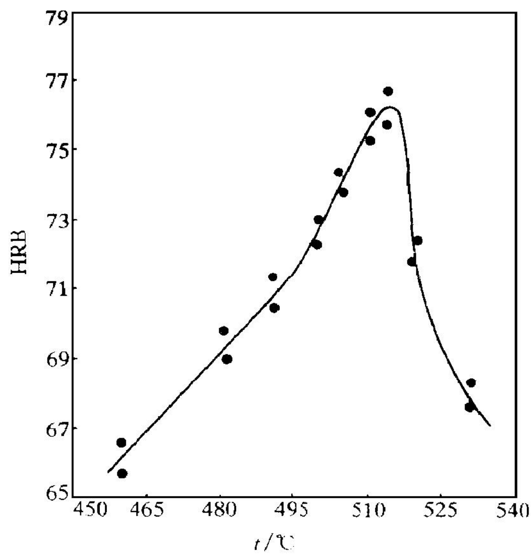

Fig.2 Relationship between hardness and solid solution temperature of 2014 aluminium alloy (natural aging)

4.3 Relationship between WJF-38 instrument's displayed values and hardness of 2014 aluminium alloy after solid solution treatment at different temperatures plus natural aging

The relationship between WJF-38 instrument's displayed values and hardness of 2014 aluminium alloy after solid solution treatment at different temperatures plus natural aging is presented in Fig.3. It is thus clear that there is a reverse "C" shape relation between WJF-38 instrument's displayed values and hardness of

2014 aluminium alloy after solid solution treatment at different temperatures plus natural aging. The reason is that with increasing solid solution temperature the WJF-38 instrument's displayed values monotonously decrease, and the hardness reaches the peak value at about 515 ℃, thus causing the reverse "C" shape relationship between the hardness and the WJF-38 instrument's displayed values.

Seen from Fig.3, the parts with insufficient solid solution, the overburnt parts and the hardening cracked parts appear at both the top and the bottom ends of the reverse "C" shape relationship. We can accurately separate the parts with insufficient solid solution whose displayed values are more than 7 000, the overburnt and the hardening crack parts whose displayed values are less than 6 400.

The experiment shows that the testing of the overburnt and cracked parts can be carried

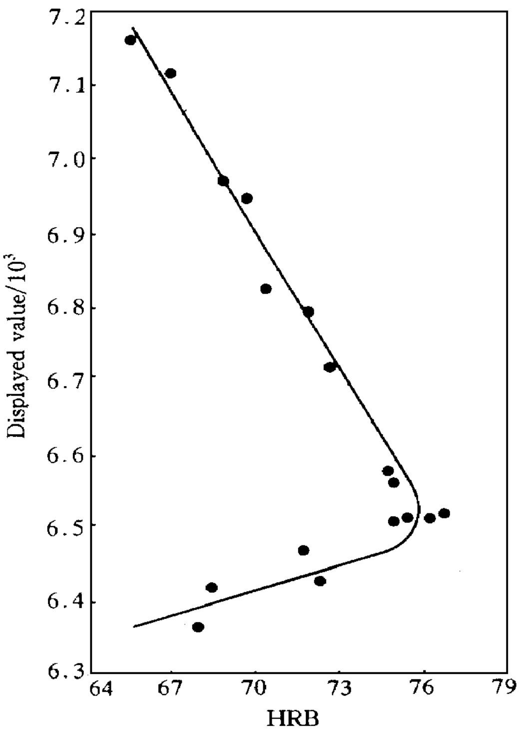

Fig.3 Relationship between hardness of 2014 aluminium alloy after solid solution at different temperatures and displayed values of WJF-38 instrument (natural aging)

out after the solid solution treatment, it can also be carried out after natural aging for a few days. This is due to the fact that although the natural aging at ambient temperature can cause the increase of aluminium alloy's hardness, it has no or little effect on electrical conductivity[9]. After the natural aging at indoor temperature of 20 ℃, the electrical conductivity drops little[4], it will not interfere with the relationship between solid solution temperature and WJF-38 instrument's displayed values.

4.4 Relationship between WJF-38 instrument's displayed values and hardness of 2014 aluminium alloy test parts after artificial aging

The relationship between WJF-38 instrument's displayed values and hardness of 2014 aluminium alloy test parts after artificial aging is presented in Fig.4, which indicates that the relationship between WJF-38 instrument's displayed values and aluminium alloy's hadness after artificial aging is a reverse "C" shape relationship[1]. It is also pointed out in Refs.[5, 10] that the electrical conductivity of over-aged aluminium alloy is higher than that of normal artificially aged parts. The factors that cause the over-aging of aluminium alloy include artificial aging time and artificial aging temperature as well. Too high an aging temperature will also cause the aluminium alloy's over-aging, that is, the decrease of its hardness, and the electrical conductivity increases with increasing aging temperature[10]. So the over-aged parts and the under-aged parts can be separated by the WJF-38 instrument. At the same time, we can also use WJF-38 instrument to research into aluminium alloys' aging technology.

The results of using WJF-38 instrument's "Y1 method" to quantitatively test 2014 aluminium alloy hardness and LC4 aluminium alloy hardness are analogous with each other[11], so the test data will not be listed again in this paper. This experiment again shows that we can use WJF-38 instrument to accurately and quantitatively test aluminium alloy parts' hardness and directly display their Brinell hardness, Rockwell hardness and Vicker's hardness values. The hardness testing precision is about HRB ±1.3, and the separating speed can reach 1 500 parts per hour.

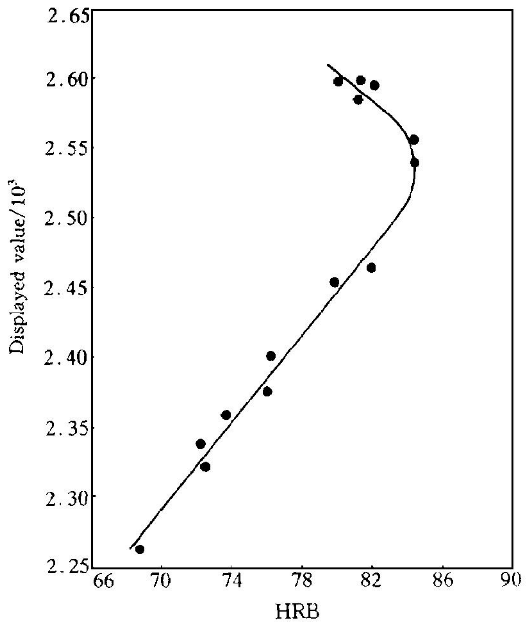

Fig.4 Relationship between hardness and WJF-38 instrument's displayed values of 2014 aluminium alloy after artificial aging

4.5 Testing of 2014 aluminium alloy parts' overburning and hardening cracks

Seen from Fig.3, when WJF-38 instrument's displayed values are less than 6 400, the relationship between displayed values and 2014 aluminium alloy test parts' hardness takes a turn. At this time, the hardness decreases with decreasing displayed values. This is caused by defects such as overburning and hardening cracks. Among them the hardening cracks' displayed values are the least.

Ref. [6] points out that, aluminium alloy's overburnt structure is formed by low-melting-point eutectic's partial melting and oxidizing that exist in crystals and boundary of grains when the alloy's heating temperature is higher than the melting temperature of low-melting-point eutectic in the alloy. The structure has a defect not allowed to emerge, because it can lead to the decline of aluminium alloy's properties such as hardness and strength. In the microscopic structure of aluminium alloy test parts heat treated at 520 ℃ and 530 ℃, we observed the overburnt features such as partial widening of the grain boundary, the re-melting balls emerging inside crystals and the obvious triangular re-melting area appearing at the juncture of grains. The overburning of the tested parts at 530 ℃ is more serious, in which the hardening cracks have already emerged. Ref. [1] points out that lattice defect may scatter electrons and decrease electrical conductivity. Vacant positions, dislocations and surface defects can also cause the decrease of electrical conductivity. Every kind of defects can cause the decrease of electrical conductivity, crack is not an exception[10]. Thus, the electrical conductivity of overburnt parts and cracked parts is lower than that of the normal qualified parts, and the WJF-38 instrument's displayed values of them are certainly less than those of normal parts. So we can use the WJF-38 instrument to rapidly discriminate and separate both the overburnt parts and the hardening crack parts. This is certainly a reliable new method for a hundred per cent nondestructive testing of quality of aluminium alloys such as 2014 which is liable to overburn during solid solution treatment. Especially, for aluminium alloys, the WJF-38 instrument's standard penetration depth can be from 3.5 mm when the frequency is 1 000 Hz to 23 mm when the frequency is 20 Hz[1], thus overcoming the shortcomings of the conventional eddy current conductivity instrument which can only test properties and defects of the superficial area and the area close to the surface. The WJF-38 instrument can test the interior properties and defects of aluminium alloy parts, and its hardness and defects testing can be hardly influenced by surface coarseness. This is an important feature of the method.

5 CONCLUSIONS

(1) WJF-38 type micro-computer-based automatic separator for metal material's quality can accurately test the quality of solid solution

treatment and aging treatment of 2014 aluminium alloy, it can also be used in the research of its heat-treatment technology process.

(2) WJF-38 instrument can be used to accurately remove defect parts of aluminium alloy such as overburnt parts and hardening crack parts.

(3) WJF-38 instrument can be used to quantitatively test aluminium alloy parts' hardness, the testing precision can reach HRB ±1.3, the testing speed can reach 1 500 parts per hour.

REFERENCES

1 Fan Jingyun and Wan Guoqing. The Chinese Journal of Nonferrous Metals, (in Chinese), 1998, 8(1): 61 - 65.
2 Wan Guoqing and Fan Jingyun. Rapid Nondestructive and Electromagnetic Testing Technology of Compositions, Hardness And Cracks of Steels and Iron. Harbin: Heilongjiang Science And Technology Press, 1996: 39 - 57.
3 Wan Guoqing and Fan Jingyun. Journal of Mechanical Engineering, (in Chinese), 1997, 33(2): 32 - 37.
4 Song Xuemeng. Analysis of Metal's Physical Property. Beijing: Mechanical Industry Press, 1990: 21, 29 - 30.
5 Xu Kebei. Nondestructive Testing, (in Chinese), 1996, 18(4): 116 - 120.
6 Light Metal Material Processing Manual Compiling Group. Light Metal Material Processing Manual, (in Chinese). Beijing: Metallurgical Industry Press, 1979: 223 - 241, 389 - 391.
7 Xiao Jimei. Alloy Phases and Phase Transformation, (in Chinese). Beijing: Metallurgical Industry Press, 1987: 247 - 249, 252 - 255.
8 Wang Xiaotian. Metal Material Science. Beijing: Mechanical Industry Press, 1987: 250 - 253, 266.
9 Coad K. Nondestructive Testing, (in Chinese), 1987, 9(4): 117 - 119.
10 American Society for Metals. Metals Handbook: Nondestructive Inspection and Quality Control. 8th Edition. Volume 11. 1976: 79, 91 - 92, 412 - 413.
11 Askeland D R. Materials Science and Engineering. Beijing: Space Aviation Press, 1988: 452 - 454.

(Edited by peng Chaoqun)