Effect of Aging Temperature on Microstructure and Mechanical Property of Aluminium Brass

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Abstract. Solution treated HAl66-6-3-2 aluminium brass was aged at different temperatures by box-type resistance furnace. The effects of aging temperature on the microstructure and mechanical properties of HAl66-6-3-2 aluminium brass were investigated. The results show that the microstructure of aging treated HAl66-6-3-2 aluminium brass is equiaxed $\beta$ phase, particle phase and dispersed precipitation phase. The precipitated phases appear and gradually increase when the aging temperature is increased. The number of precipitated phase is most at 400°C aging temperature. As the aging temperature increases continuously, the number of precipitated phase decreases and the size of precipitated phase increases, the hardness of aluminium brass presents a trend of rising first and then decreasing, the wear loss of aluminium brass presents a trend of decreasing first and then rising. When the aging temperature is 400°C, the hardness of aluminium brass reaches the maximum value of 320HV1 and the wear loss reaches the minimum value of 0.4065g. Observing the wear profile, the wear mechanism of the alloy is mainly abrasive wear under dry friction conditions.

1. Introduction
Brass has excellent hot, cold processing properties and corrosion resistance. It is a kind of the most widely used copper alloys, but poor strength and wear resistance limits its application range [1]. HAl66-6-3-2 aluminium brass is Cu-Zn-Al-Fe-Mn series multi-component brass. Good comprehensive mechanical properties can be strengthened by heat treatment. It can be used to make wear-free parts such as lubrication-free bushings and guide grooves [2].

The aging treatment is a heat treatment process which the non-ferrous metal is subjected to solution treatment and then kept at room temperature or higher for a certain period of time. Precipitated phases appears in solid solution after aging treatment. It can improve the strength and hardness [3]. In this paper, the law of aging temperature on the microstructure and mechanical properties of HAl66-6-3-2 aluminium brass is investigated. We hope that we can get a best heat treatment process of HAl66-6-3-2 aluminium brass.

2. Materials and methods
The compositions(wt\%) of HAl66-6-3-2 aluminium brass in this experiment are as follows: 64.0766\% Cu, 3.266\% Fe, 2.008\% Mn, 0.063\% Pb, 0.105\% Si, 6.565\% Al, the residual content is Zn. The heat
treatment was conducted in a box-type resistance furnace. The aluminium brass was conducted solution treatment with 860°C /1h/WC process parameters. And then we cut the sample on the solid solution sample by wire cutting. Finally, Mechanical properties and metallographic specimens were cut on aged samples of different aging temperatures. The aging treatment process is shown in Table 1.

The wear experiment was carried out on the MMP-2 ring-block wear testing machine. The material of ring specimen is 45 steel. The hardness of 45 steel is 40 HRC. The text force is 2 kN. The rotating speed is 200r/min. According to GB/T 4340.1-2009 standard, Vickers hardness test was carried out on samples at different aging temperatures. Measuring scale of Vickers hardness is HV1. The microstructure of aluminium brass was observed under the optical microscope. The corrosive agent is a kind of FeCl3-HCl-C2H5OH solution. Semi-quantitative analysis of phase components in the microstructure was carried out by EDS. The wear surface morphology was observed with SEM in order to investigate the wear mechanism of HA166-6-3-2 aluminium brass in ring-block wear test condition.

| Number | Aging temperature(°C) | Holding time (h) | Cooling mode |
|--------|------------------------|------------------|--------------|
| 1      | 320                    | 2                | AC           |
| 2      | 360                    | 2                | AC           |
| 3      | 400                    | 2                | AC           |
| 4      | 440                    | 2                | AC           |
| 5      | 480                    | 2                | AC           |

3. Results and discussion

3.1. Microstructure Analysis

The microstructure of HA166-6-3-2 aluminium brass at different aging temperatures is shown in Figure 1. We can see that the microstructure of aging treated HA166-6-3-2 aluminium brass is equiaxed β phase, particle phase and dispersed precipitation phase. The Figure 2 is the detection position. The results of three kinds of phase which was detected by EDS are shown in table 2. We find that the main elements of the matrix phase and the precipitated phase have the same composition consist of Al, Mn, Fe, Cu, Zn element and the content of Cu, Zn element is more than other element enough. The content of Cu, Al element in the precipitated phase is more than the matrix phase. The content of Mn, Zn element in the precipitated phase is less than the matrix phase. The content of Fe element in matrix phase is equivalent to the content of Fe element in precipitated phase. The particle phase is mainly composed of Al, Mn, Fe, Cu, Zn and Si. The Fe, Al, Cu are the main elements. The precipitated phase appears and gradually increases when the aging temperature increases. The number of precipitated phase is most at 400°C aging temperature. As the aging temperature increase continuously, the number of precipitated phase decreases and the size of precipitated phase increases. This is because the solid solution is in a metastable supersaturated state. When a certain temperature is maintained for a certain period of time, the second phase resolves. The decomposition process of supersaturated solid solution depends on the decomposition temperature [4, 5]. At 320°C aging treatment, the solute atoms diffuse slowly and the precipitates form slowly. Macroscopically, the number and the size of precipitated phases is small. As the aging temperature increases, the diffusion rate of solute atoms is accelerated and the GP area is increased. As time progresses, GP grows up to precipitate phase. The macroscopic performance is an increase in the number of precipitated phases and a slight increase in size. Continue to increase the aging temperature, adjacent small precipitates begin to gather and grow up. Macroscopically, the size of the precipitated phase becomes larger and the number of precipitated phase becomes less.
Figure 1. Microstructure of HAl66-6-3-2 aluminium brass at different aging temperature 500×, (a) tempering at 320°C; (b) tempering at 360°C; (c) tempering at 400°C; (d) tempering at 440°C; (e) tempering at 480°C

Figure 2. EDS detection location of HAl66-6-3-2 aluminium brass.
Table 2. Results of EDS (wt %).

| Type of phase   | Al  | Mn  | Fe  | Cu  | Zn  | Si |
|-----------------|-----|-----|-----|-----|-----|----|
| Matrix phase    | 6.25| 2.71| 2.20| 64.51| 24.33| /  |
| Precipitated phase | 11.41| 1.71| 2.17| 66.52| 18.19| /  |
| Particle phase  | 15.74| 5.96| 63.61| 11.64| 2.25| 0.8|

3.2. Hardness Analysis

The hardness of HAl66-6-3-2 aluminium brass at different aging temperatures is shown in Table 3. From Table 3, the hardness of the aged samples varies from 288HV1 to 320HV1. As the aging temperature increases, the hardness of aluminium brass presents a trend of rising first and then decreasing. When the aging temperature is 400°C, the hardness of aluminium brass reach the maximum value of 320HV1. The properties of the alloy depend mainly on the matrix structure and the morphology, size and distribution of the phases [6, 7]. Dispersion strengthening is distributed through the hard precipitated phase to the matrix to improve the strength or hardness. The finer the particles, the more dispersed and evenly distributed, the better the strengthening effect. In this study, supersaturated solid solution with metastable structure is excited by external energy input. It lead to the migration and aggregation of solute atom and then form granular precipitate phase. From Fig.1(c), we can see that when the aging temperature is 400°C, the size of the precipitated phase is small, the largest, and the most diffuse. At this time, the hardness value of HAl66-6-3-2 is best. As the aging temperature increases, the number of precipitated phases begins to decrease, the size of the precipitated phase becomes larger and the diffusion becomes lower. This phenomenon reduces the hardness of the aluminium brass.

Table 3. Results of hardness test (HV1).

| Number | Hardness value1 | Hardness value2 | Hardness value3 | Hardness value4 | Hardness value5 | Average |
|--------|-----------------|-----------------|-----------------|-----------------|-----------------|---------|
| 1      | 307             | 310             | 298             | 298             | 290             | 301     |
| 2      | 312             | 319             | 313             | 316             | 309             | 314     |
| 3      | 323             | 334             | 312             | 329             | 303             | 320     |
| 4      | 293             | 297             | 288             | 292             | 290             | 292     |
| 5      | 287             | 285             | 290             | 293             | 287             | 288     |

3.3. Wear Analysis

The wear loss of HAl66-6-3-2 aluminium brass at different aging temperatures which was carried out on the MMP-2 ring-block wear testing machine is shown in Table 4. The wear loss of the aged samples varies from 0.4065g~0.5615g. As the aging temperature increases, the wear loss of aluminium brass presents a trend of decreasing first and then rising. When the aging temperature is 400°C, the wear loss of aluminium brass reach the minimum value of 0.4065g. The wear resistance of the material depends on the hardness to some extent. Generally, the higher the hardness value and the better wear resistance. In addition, the wear properties of the alloy also depend on the composition, size and distribution of the phases in the structure [8]. In this study, Aluminium brass and 45 steel friction pair are in dry friction state. During the process of increasing the aging temperature, the number of precipitated phase in the microstructure increases, and the degree of dispersion is good, reaching a peak at 400°C. The appearance of precipitates has a positive impact on wear resistance. The reason is that the relatively soft matrix in the aluminium brass is worn first in the contact surface and then precipitation occurs is worn successively. Due to the large number of precipitated phases, small size and hard texture, the wear process is delayed. Observing the wear profile, we find a variety of grooves in the appearance of wear. This indicates that under dry wear conditions the wear mechanism of the aluminium brass/45 steel friction pair is mainly abrasive wear.
Table 4. Results of wear test (g).

| Number | 1    | 2    | 3    | 4    | 5    |
|--------|------|------|------|------|------|
| Wear loss | 0.5245 | 0.4207 | 0.4065 | 0.5615 | 0.5445 |

Figure 3. Wear profile.

4. Conclusion

(1) The microstructure of aging treated HAl66-6-3-2 aluminium brass is equiaxed β phase, particle phase and dispersed precipitation phase. The number of precipitated phase is most at 400°C aging temperature. As the aging temperature increase continuously, the number of precipitated phase decreases and the size of precipitated phase increases.

(2) As the aging temperature increased, the hardness of aluminum brass presented a trend of rising first and then decreasing and the wear loss of aluminium brass presented a trend of decreasing first and then rising. At 400°C, the hardness of aluminium brass reaches the maximum value of 320HV1 and the wear loss reaches the minimum value of 0.4065g.

(3) Under dry wear conditions the wear mechanism of the aluminium brass/45 steel friction pair is mainly abrasive wear.

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