Mechanical properties of novel heat-treatment-free aluminium alloys

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With the booming development of new energy vehicles, integrated die casting has become an important means of automotive parts manufacturing, and there is an urgent need for age-free heat-treated aluminium alloys in the industry. Therefore, a new ageing-free heat-treated aluminium alloy was developed to analyses the difference in mechanical properties before and after heat treatment and its mechanism. When the new aluminium alloy is not aged, the tensile strength is 278.78MPa, which is 92.2% of that after aging; the yield strength is 122.65MPa, which is 64.39% of that after aging; and the elongation rate is 8.89% which is 126.8% of that after aging, which meets the needs of application. The reason for the excellent performance of the new aluminium alloy is that the new aluminium alloy can precipitate enhanced phase Mg2Si, α2-Al phase and eutectic Si without aging treatment.

Keywords: Aluminium alloys; High-pressure die casting; Aging heat treatment; Body lightweighting.

1. Introduction

In order to achieve automotive lightweight, reduce carbon emissions, aluminium alloy materials in the automotive industry application is becoming more and more popular. And integrated die casting technology will be a number of scattered parts highly integrated into a casting, one-step molding eliminates the split stamping, welding and assembly of the complex process, greatly reduces the manufacturing cost, and allows the manufacture of more complex structure of the product, become an important means of automotive aluminium alloy parts manufacturing [1]. Usually aluminium alloy parts manufacturing is completed, the need for aging heat treatment, that is, the parts are heated to and kept warm for a period of time, at this time the aluminium alloy in the supersaturated solid solution occurs desolvation, precipitation of the second phase or the formation of hard solute atoms of the clusters, the formation of reinforcing phases, strength and hardness increase [2-3]. However, the product form size of integrated die casting is large, and the heat treatment process is easy to cause deformation, dimensional changes and surface defects. Therefore, aluminium alloy without aging heat treatment has become a hot spot for research. Currently commonly used heat treatment-free casting aluminium alloys are mainly divided into two categories, Al-Si system and Al-Mg system alloys, with tensile strength of about 200-300 MPa and elongation of about 7%-12% [4-5]. In this study, a new aging-free aluminium alloy in China is taken as the research object to carry out mechanical property testing, microstructure characterization and chemical composition detection, and comparative analysis with the mechanical properties and organization after aging to reveal the high-performance mechanism of the new aluminium alloy.

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2. Materials and experiments

2.1. *Material chemical composition and mechanical property test*

The material used in this study is a new type of aluminium alloy developed based on AlSi10MnMg alloy, which belongs to the Al-Si system of alloys, and it possesses stronger comprehensive performance through the fine-tuning of elemental compositions as well as the improvement of the production process. The main chemical composition was analyzed by spectrometer and the results are shown in Table 1 below, and the conventional AlSi10MnMg composition is shown in Table 2. The new aluminium alloy has been fine-tuned on this basic composition, as shown in the following: the content of Fe, Ti, Zn and Cu is reduced, a small amount of Sr is added, and the content of Mn is increased. The increase in the content of Mn helps to strengthen the alloy, because Mn can form a more stable eutectic phase with Si, which improves the heat resistance and strength of the alloy. In addition, the high content of Mn helps to refine the grain, improve the casting performance of the alloy, reduce the tendency of hot cracking, and also improve the corrosion resistance of the alloy to a certain extent. For the mechanical property test, the size of the sample is shown in Figure 1, and four kinds of samples are prepared, which are 3mm thick test plate, 4mm thick test plate, 5mm thick test plate and 6.3mm diameter bar, and the alloy specimens are subjected to surface trimming, burr removal treatment, and then tensile stretching, and after the completion of the tensile stretching, the samples are taken for the observation of the microstructure.

Table 1 Main components of new aluminium alloys (%)

Element	Si	Mn	Mg	Fe	Ti	Zn	Sr	Al
Content (%)	10.85	0.659	0.253	0.125	0.065	0.017	0.0157	Other

Table 2 AlSi10MnMg aluminium alloy chemical composition standard requirement

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
Content (%)	9.0-11.5	0.25	0.05	0.40-0.80	0.10-0.60	0.07	0.20	Other

2.2. *Ageing heat treatment process*

Although non-heat-treated aluminium alloys are designed to achieve good properties without conventional heat treatment, in order to better evaluate the properties of this new type of aluminium alloy, it was subjected to a low-temperature ageing treatment to enhance its properties, compare the microstructures of the two and investigate the mechanism of the enhancement of the mechanical properties by the microstructure of this aluminium alloy. For most aluminium alloys, the optimum temperature range for low-temperature ageing may be between 100°C and 150°C. This is because in this temperature range, the formation of beneficial aging phases (e.g., θ' or GP zones) can be promoted while the precipitation of coarse phases can be avoided, thus maintaining better overall mechanical properties. Therefore, combined with the previous study, the low-temperature aging treatment condition was set at 155°C, holding time of 12 hours, followed by air cooling, and the process curve is shown in Fig. 2.

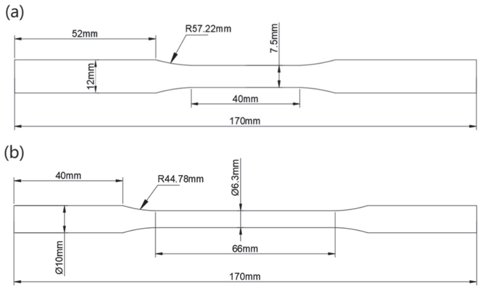

Fig. 1. Aluminum alloy tensile pattern

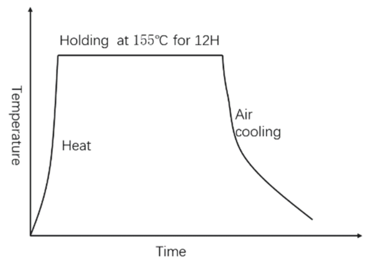

Fig. 2. Aging treatment process

3. Results and analyses

3.1. *Mechanical properties*

Figure 3 shows the mechanical properties test results, it can be seen that the tensile strength of aluminium alloy of different thicknesses without heat treatment specimens are not significant difference are in about 280MPa, elongation is also basically maintained at about 7%. After aging treatment, the tensile strength and yield strength of aluminium alloy are improved, but the elongation rate decreases. 3mm thick specimen plate after aging treatment, the tensile strength is improved by about 10%, the yield strength is improved by about 27%, but the elongation rate decreases by about 26%; 4mm thick specimen plate, the tensile strength is improved by about 7.7%, the yield strength is improved by about 100%, and the elongation rate decreases by about 30.5% or so; the tensile strength of the 5mm thick specimen increased by about 7.3%, the yield strength increased by about 72%, and the elongation decreased by about 27%.

Compared with the plate specimen, the elongation of the bar letter specimen is better, and there is no big difference between the tensile strength and yield strength of the two. The tensile strength of the bar specimen without aging treatment is 278.78MPa, which reaches 92.2% after aging, the yield strength is 122.65MPa which reaches 64.39% after aging, and the elongation is 8.89% is 126.8% after aging. Aluminium alloy AlSi10MnMg commonly used in industry performance as shown in Table 3, compared with the new aluminium alloy tensile strength is better than the heat-treated AlSi10MnMg, yield strength is slightly lower than the T5 state of the AlSi10MnMg, elongation is only lower than the T7 state of the AlSi10MnMg. As seen in the new aluminium alloy performance basically can achieve the traditional AlSi10MnMg aluminium alloy after heat treatment.

Table 3 Standard requirements for mechanical properties of AlSi10MnMg aluminium alloy

	Heat treatment status	Tensile strength (MPa)	Yield strength (MPa)	Elongation rate (%)
F	Free state	≥200	≥120	≥5
T5	Solution Treatment+incomplete artificial aging	≥270	≥150	≥4
T7	Solution treatment+artificial aging	≥200	≥120	≥12

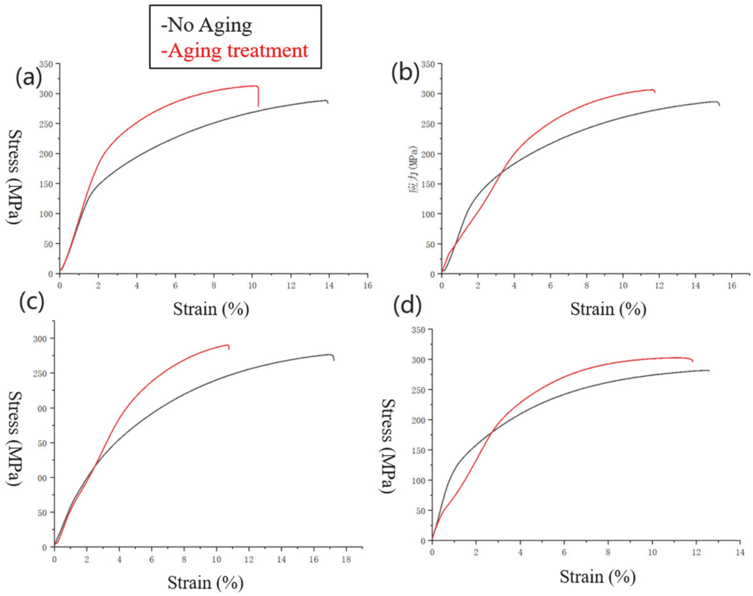

Fig. 3 Stress-strain curves of aluminium alloys with different thicknesses: (a) 3 mm test plate; (b) 4 mm test plate; (c) 5 mm test plate; (d) rod.

Figure 4 is the test fracture photo, visible aluminium alloy fracture is not flush, uneven section, section color partly grey, partly bright, with obvious granularity as well as some cracks, and the shear lip is not obvious, so it is initially judged to be a mixture of brittleness and toughness of the fracture. And also, can be seen from Figure 3-5 (e) (f) two diagrams, 5mm thick aluminium alloy specimen with a lot of internal porosity, the existence of porosity, resulting in the reduction of the organizational density of the aluminium alloy casting, which affects its tensile strength, yield strength and toughness and other mechanical properties.

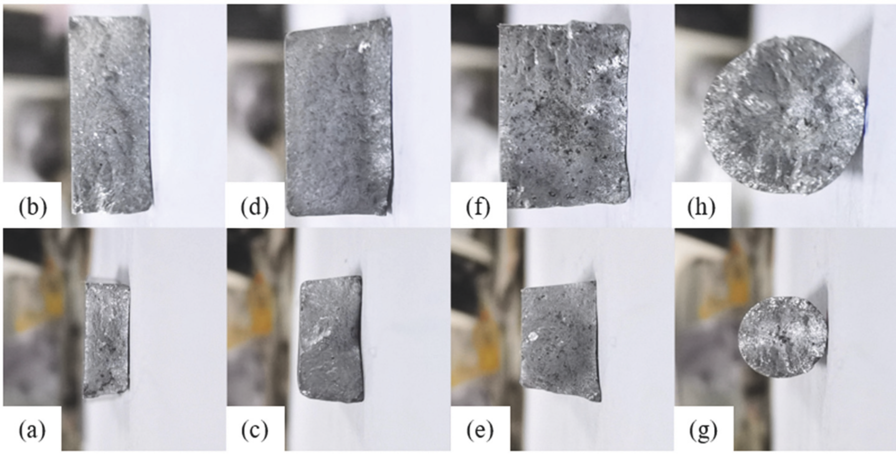

Figure 4. (a) 3 mm, unaged; (b) 3 mm aging treatment; (c) 4 mm unaged; (d) 4 mm aging treatment; (e) 5 mm unaged; (f) 5 mm aging treatment; (g) rod, unaged; (h) rod, aging treatment

3.2. *Microstructural characterization*

Finally, the microstructures of the samples were examined, and as can be seen in Figure 5, regardless of whether the samples have undergone aging heat treatment or not, the microstructures of the aluminium alloy samples are the same, with the coarse α1-Al phase, the fine and rounded α2-Al phase, and unevenly dispersed stubby and granular eutectic Si, of which the α1-Al phase exists in the form of coarse grains, whereas the α2-Al phase shows a more regular fine rounded profile. The shape of α1-Al phase is not regular, and its coarse and irregular shape restricts the growth of eutectic Si, forcing it to change its growth path frequently and to aggregate into relatively closed clusters.

Figure 6 shows the SEM photographs of the aluminium alloy with or without ageing treatment, and Figure 7 shows the XRD inspection results of the material. Comparison of Fig. 6(a)(b) shows that there are smaller granular phases in the grey area in (a), and granular reinforcing phases are also found in (b), and there are also larger lumps of phases in the colleague. Combined with the analysis of the x-ray diffractograms in Figures 4-9 below, it can be seen that the precipitated phase is the reinforcing phase Mg2Si. Combined with the analysis of the composition of the aluminium alloys, both Mn and Mg are able to form a composite phase with Si to improve the strength, and the eutectic phase formed by Mn and Si is relatively stable, and a high content of Mn is also able to refine the grains. A moderate amount of Mg not only meets the need to form sufficient Mg2Si reinforced phase, but also avoids premature precipitation or the formation of coarse phase due to high Mg content.

The fine and uniformly distributed Mg2Si phase will act as a pinning agent during dislocation movement and increase the resistance to dislocation slip, thus significantly increasing the strength and hardness of the alloy. This strengthening mechanism does not require a significant sacrifice of the plasticity of the material, which is conducive to obtaining good overall mechanical properties. The precipitated phases can also effectively hinder crack extension and improve the fracture toughness of the material. When the crack encounters these fine particles, it requires more energy to bypass or pass through them, which helps to improve the crack extension resistance and durability of the material.

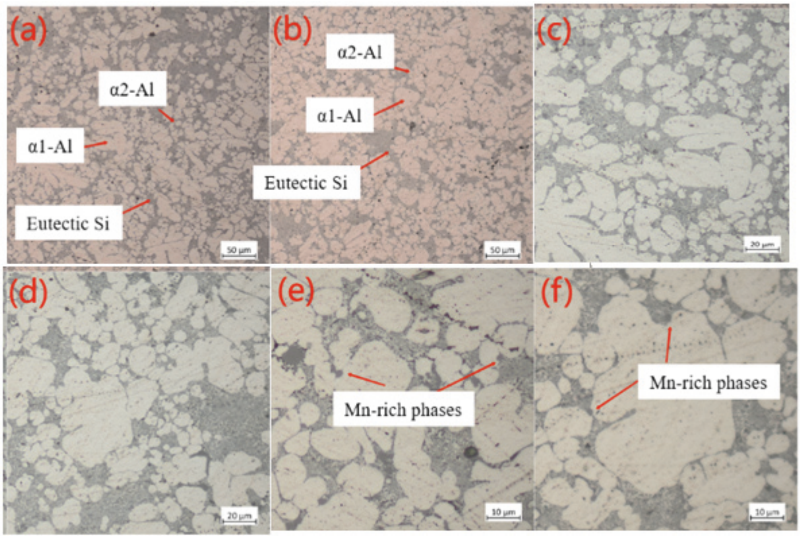

Fig. 5. Metallographic diagram of aluminium alloy organisation of bar (a) X200 unaged (b) X200 aged (c) X500 unaged (d) X500 aged; (e) X1000 unaged (f) X1000 aged.

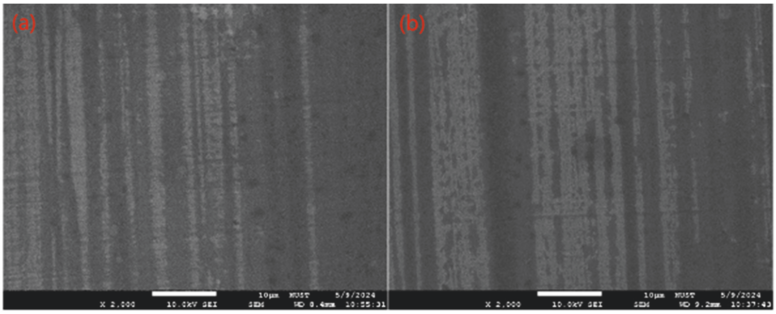

Fig. 6.SEM map photographs of (a) normal condition; (b) aging treated condition

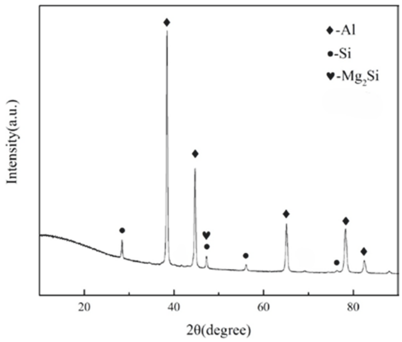

Fig. 7. x-ray diffractogram of aluminium alloy

4. Conclusion and prospect

(1) The mechanical properties of the new ageing-free aluminium alloy were tested, and it was found that its tensile strength was greater than or equal to 260MPa, between 260MPa and 280MPa; its yield strength was greater than or equal to 110MPa, between 110MPa and 140MPa; and its elongation rate was about 7%, which reached the performance of traditional AlSi10MnMg aluminium alloy after heat treatment.

(2) The tensile strength of the new aluminium alloy bar specimen is 278.78MPa, which reaches 92.2% after aging, the yield strength is 122.65MPa which reaches 64.39% after aging, and the elongation is 8.89% which is 126.8% after aging. The reason lies in the fact that the new aluminium alloy does not need to be aging processed, and it can precipitate out the reinforcing phases of Mg2Si, α2-Al phases, eutectic and others.

References

1. Santos, Mário C. Machining of aluminum alloys: a review. The International Journal of Advanced Manufacturing Technology,2016:3067-3080.
2. Zhang W, Xu J. Advanced lightweight materials for Automobiles: A review. Materials & Design,2022,221:110994.
3. Bao ZJ, Yang HY, Dong BX, et al. Development Trend in Composition Optimization, Microstructure Manipulation, and Strengthening Methods of Die Steels under Lightweight and Integrated Die Casting. Materials,2023,16(18):6235.
4. Chang CC, Yang JG, Qi L, et al. Optimization of heat treatment parameters with the taguchi method for the a7050 aluminum alloy. Advanced Materials Research,2010,139:157-162.
5. Monica V, Lakshmikanth G, Lathicashree S, et al. An experimental analysis and optimization of heat treatment parameters of Al6061 alloy for improved mechanical properties. International Journal of Mechanical and Production Engineering Research and Development,2019,9:46-59.