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Research Article

Characteristics Improvement by Inclusion of Phosphorous in AL-20SI

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This study study focused on enhancing the mechanical properties of hypereutectic Al-Si alloys through the addition of phosphorus (P). The research investigated how different levels of phosphorus affected the alloy's microstructure and mechanical characteristics. Results showed that phosphorus effectively refined the coarse primary silicon crystals and modified large needle-like eutectic silicon into finer fibrous or lamellar structures. However, excessive phosphorus had adverse effects on primary silicon refinement. Alloys with 0.02% to 0.03% phosphorus demonstrated optimal grain size and improved mechanical properties compared to unmodified alloys. Specifically, the Vickers hardness decreased from 81 to 57, indicating increased plasticity, strength, and wear resistance.

Keywords: Al-Si alloy, phosphorus, plasticity, strength, wear resistance.

1. Introduction

Hypereutectic Al-Si alloys are highly valued for their exceptional properties, including excellent wear and corrosion resistance, high temperature strength, low coefficient of thermal expansion, good cast performance, and high specific strength. These alloys find extensive applications in industries such as aerospace, automotive, and astronautics. However, conventional casting methods often result in alloys with a microstructure characterized by coarse primary silicon crystals within a fibrous eutectic matrix. The brittleness of these coarse silicon crystals, both in the eutectic and primary form, significantly compromises the alloy's mechanical properties by promoting premature crack initiation and fracture under tension.

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To address this issue, various techniques have been explored to refine the primary silicon crystals. These methods include high-pressure casting, rapid solidification techniques, and melt overheating treatments. In the current study, the focus was on the complex modification of the alloy using phosphorus (P) addition.

Objective of the work

[1] To characterize Al-20 Si ,A1-20 Si+0.02 P, to Al-20 Si+0.15

[2] Measurement of Hardness in Percentage of “P” in Al-20Si

[3] To study the wear characteristics of Al-20Si and Al-20Si+002P

2. Experimental in Detail

The preparation of Al-20Si alloy involves melting calculated quantities of commercially pure aluminum (99.7% purity) and Al-20%Si master alloy using a foundry technique. This is done in a resistance furnace under a cover flux comprising 45% NaCl, 45% KCl, and 10% NaF. The melt is maintained at 720˚C ± 50˚C. After degassing the melt with solid hexachloroethane (C2Cl6), CuP chips enclosed in aluminum foil are added to facilitate grain refinement. The melt is then stirred for 30 seconds using a zircon-coated iron rod, following which no further stirring is conducted. Subsequently, the melt is poured into cylindrical graphite molds (25 mm diameter and 100 mm height) surrounded by fire clay bricks, with the top left open for pouring.

Fig.1. Casting furnace

Fig.2. Hardness specimen

Fig.3. Casting furnace

Fig.4. Casting mould

The resulting samples are then subjected to measurements of hardness, wear characteristics, and primary Si particle sizes. The optimal addition of phosphorus to the melt is determined during this process, which will be utilized for subsequent research endeavors.

3. Process

When phosphorus (P) is introduced into the melt of hypereutectic Al-Si alloys, it triggers a reaction where aluminum (Al) combines with phosphorus to form aluminum phosphide (AlP). This reaction is crucial in modifying the microstructure of the alloy during solidification. AlP serves as heterogeneous nucleation sites for primary silicon particles.

In simpler terms, the addition of phosphorus helps refine the primary silicon particles during the solidification process of hypereutectic Al-Si alloys. This refinement enhances the overall properties of the alloy, making it more suitable for various applications.

4. Measurement of Hardness

Table 1. Vickers Hardness number for various composition of alloy

Composition of alloy	Vickers Hardness No.	Composition of alloy	Vickers Hardness No.
Al-20Si+ 0P	81	Al-20Si+0.08P	57
Al-20Si+0.01P	72	Al-20Si+0.09P	70
Al-20Si+0.02P	65	Al-20Si+0.10P	70
Al-20Si+0.03P	69	Al-20Si+0.11P	67
Al-20Si+0.04P	77	Al-20Si+0.12P	74
Al-20Si+0.05P	81	Al-20Si+0.13P	71
Al-20Si+0.06P	72	Al-20Si+0.14P	64
Al-20Si+0.07P	75	Al-20Si+0.15P	65

Table 2. Volume Loss with respect to Normal pressure

Normal pressure (MPa)	Al-20Si	Al-20Si+0.02%P
0.195	1.0584	0.9854
0.39	1.8248	1.7518
0.584	2.2993	2.2263
0.78	2.3358	2.2993
0.975	3.2847	3.2117
1.17	5.7664	5.6934

From the above hardness table it is very much clear that the optimum addition of phosphorous the hardness of the specimen Al-20Si+0.08P. The hardness decreases Vickers hardness number from 81 to 57. And hence there is a decrease in hardness at optimum addition which means as hardness decreases and tensile strength, Plasticity increases.

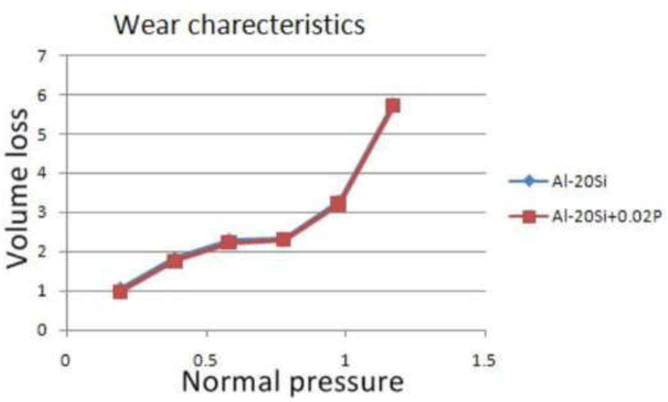

Fig.5. Volume Loss with respect to Normal pressure

Table 3. Volume Loss with respect to Sliding speed dependent

Sliding speed dependent (m/min)	Al-20Si	Al-20Si+0.02%P
0.942	2.1533	2.0803
1.884	3.2847	3.2117
2.827	1.3139	1.2409
3.768	0.6934	0.5839

Fig.6. Volume Loss with respect to Sliding speed dependent

By conducting different kinds of test on the prepared samples of Al-20Si , each test is analyzed separately and results are drawn Vickers hardness test has been conducted and observed comparatively less hardness Optimum addition of Phosphorous for Al-20Si is 0.08 % P which is justified by the decrease in hardness from 81 VHN to 57 VHN. Which in turn increases plasticity.

Wear characteristics is also studied by conducting experiments at varying

i. Normal pressure
ii. Sliding speed
iii. Sliding distance

5. Conclusions

The addition of phosphorus (P) to hypereutectic Al-Si alloys has a complex modification effect on the primary silicon particles. The refinement effect of phosphorus on primary silicon becomes more pronounced as the P content increases. However, there is an optimal range for the addition of P, typically between 0.02% and 0.08%. Within this range, the size of primary silicon decreases, leading to improved mechanical properties of the alloy.

Exceeding the optimum P content, particularly beyond 0.08%, becomes detrimental to the refinement of primary silicon. In such cases, the average particle size increases, diminishing the beneficial effects of P addition on the alloy's properties.

In terms of mechanical properties, the addition of P improves the hardness of hypereutectic Al-Si alloys. However, an optimal combination of strength and plasticity is achieved when the alloy contains around 0.08% P. This is evidenced by a decrease in hardness, indicating an increase in plasticity.

Furthermore, the wear resistance of the alloy is marginally increased by the addition of 0.02% P. Therefore, the optimal addition of phosphorus for Al-20Si alloys is 0.08%, as justified by the achieved decrease in hardness and the resulting increase in plasticity, along with the improved wear resistance.

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