Effect of Silicon on Microstructure and Properties of Cr12 High Chromium Cast Iron

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Abstract: This study aims to investigate the influence of varying silicon content on the microstructure and mechanical properties of both as-cast and heat-treated high chromium cast iron with 12 wt.% Cr. The findings demonstrate that an increase in silicon content leads to a higher proportion of eutectic carbide in the as-cast structure, accompanied by a gradual refinement in carbide size. Moreover, an elevated silicon content enhances the hardness of as-cast samples, with 2.7Si exhibiting a hardness of 46.8 HRC, which is 2.2 HRC higher than the lowest hardness sample- 1.3Si. Following salt bath heat treatment, the microstructure of high chromium cast iron primarily consists of bainite, pearlite, retained austenite, secondary carbide, and eutectic carbide. Furthermore, an increased silicon content improves both surface hardness and wear resistance. Specifically, at 2 mm from salt bath treatment for the 0.8Si sample exhibits a hardness value of 59.9 HRC; whereas when the silicon content increases to 2.7 wt%, the sample's hardness reaches up to 60.8 HRC after salt bath heat treatment.

Keywords: high chromium cast iron, Si, hardness, wear resistance

1 Introduction

High chromium cast iron exhibits exceptional hardness and superior wear resistance, making it a crucial component in various applications such as ball mills, crushers, and metal rolling mills[1,2]. However, the elevated cost of chromium often leads to higher expenses associated with high chromium cast iron. To address this issue, incorporating silicon into the alloy can be considered as a viable strategy to enhance both the utilization rate of chromium and the wear resistance of chromium white cast iron. Silicon is a common element in high chromium cast iron, which is introduced into castings along with casting raw materials. Not only does silicon possess excellent deoxidation properties but it also effectively prevents the loss of chromium during oxidation processes. Moreover, silicon influences the cooling process by shifting the eutectic point towards lower temperatures, narrowing down the temperature range for eutectic reactions while refining eutectic carbides and austenite dendrites. Numerous studies have demonstrated that an increase in silicon content results in higher carbide content within high chromium cast iron along with finer carbide structures, thereby contributing to improved wear resistance [3-5]

This study focuses on investigating the effects of varying silicon content on the microstructure and mechanical properties of both as-cast and heat treated Cr12 high chromium cast iron. Furthermore, the impact of salt bath isothermal treatment on the microstructure and properties of high chromium cast iron is examined. The goal is to obtain high chromium cast iron with improved wear resistance by adding appropriate silicon elements.

2 Experimental procedure

Five high chromium cast irons with 12 wt.% Cr and varying silicon contents were cast into Y-shaped test blocks. Their chemical compositions are indicated in Table 1. Subsequently, these test blocks underwent salt bath isothermal heat treatment.

The microstructure and properties of the cast iron are characterized and analyzed using X-ray diffractometry, optical microscopy, scanning electron microscopy, and laser confocal microscopy.

The friction and wear behavior of salt bath treated specimens was measured by MFT-5000 Rtec multifunctional friction machine. Finally, MLD-10 dynamic load impact abrasive wear testing machine was used to characterize the impact abrasive wear resistance of salt bath treated samples. The impact abrasive wear sample was sampled from Cr12 high chromium cast iron samples 2 mm from the ionized salt bath interface.

Table 1. Chemical Composition of the studied high chromium cast iron

No.	C	Cr	Si	Ni	Mn	P	S
S1	2.75	12.43	0.78	0.103	0.549	0.019	0.023
S2	2.71	12.27	1.27	0.102	0.547	0.019	0.023
S3	2.67	12.21	1.62	0.076	0.525	0.020	0.016
S4	2.63	12.20	2.14	0.075	0.528	0.020	0.016
S5	2.58	12.05	2.70	0.074	0.525	0.020	0.016

3 Result and discussion

The cast high chromium cast iron exhibits a typical hypoeutectic structure, consisting of dendritic pearlite and interdendritic eutectic clusters. The eutectic structure is composed of M_7C_3 carbide and pearlite. With an increase in silicon content, the carbide content increases, and the size of the carbides gradually refines, thereby enhancing the hardness of the cast iron. Among the as-cast samples, 1.3Si exhibited the lowest hardness at 44.6 HRC, while 2.7Si demonstrated the highest hardness at 46.8 HRC

Ater undergoing salt bath treatment, the matrix structure of high chromium cast iron was achieved through isothermal quenching involving bainite and residual austenite. The granular secondary carbides present in the matrix are identified as $M_{23}C_6$ carbides. On the quenched surface, the matrix consists of bainite and residual austenite. As the depth of quenching increases, pearlite emerges within the matrix. In low silicon and high chromium cast iron, there is a relatively low content of pearlite observed. However, in high silicon and high chromium cast iron, an increase in quenching depth leads to a corresponding increase in pearlite formation. Notably, at 25m from the quenching interface for the 2.7Si sample, bainite disappears entirely while pearlite becomes predominant within the matrix.

The silicon content increase leads to a gradual enhancement in the hardness of the cast iron surface. The 0.8Si sample shows a measured hardness of 59.9 HRC at 2 mm from the quenching interface, while increasing the silicon content to 2.7 wt. % results in a hardness of 60.8 HRC at the same distance. Additionally, there is a continuous decline in hardness as samples move away from the quenching interface for similar silicon content levels. When the silicon content exceeds 2.1 wt. %, there is an abrupt decline in hardness indicating poor hardenability for cast iron with high silicon content ≥2.1 wt. %. The difference in hardness between samples with 0.8Si at distances of 2 mm and 25 mm from the quenching interface is only measured to be 0.5 HRC; however, this difference significantly increases to around 1.1 HRC when silicon content rises to approximately l.6 wt. %. When the silicon content increases again, the hardness of the sample decreases significantly with the increase of depth, and the hardness of the 2.7Si sample at 25mm from the quenching interface is only 49.5HRC.

The results of the impact abrasive wear test demonstrate a gradual decrease in sample wear weight with increasing silicon content, followed by a slight increase at 2.7 wt.% silicon. Notably, when the silicon content reaches 2.1 wt.%, the sample exhibits the lowest wear weight loss of 102 mg, which accounts for approximately 77.3% of the wear weight loss observed in the 0.8Si sample. Subsequently, as the silicon content continues to increase, there is a small rise in sample wear weight loss while maintaining overall stability.

4 Conclusion

(1) The microstructure of cast iron is mainly composed of pearlite and M_7C_3 type eutectic carbide. With the increase of silicon content and eutectic carbide content, the hardness of cast iron is increased.

(2) After salt bath isothermal heat treatment, the microstructure of high chromium cast iron is mainly composed of bainite, residual austenite, secondary carbide and eutectic carbide. With the increase of silicon content, the hardness of cast iron sample surface gradually increased, but the hardenability gradually decreased. When the silicon content ≥2.1 wt.%, the hardenability of cast iron was poor.

(3) After undergoing salt bath heat treatment, the impact abrasive wear resistance of high chromium cast iron gradually improves with an increase in Si content, reaching a stable state when the Si content exceeds 2.1 wt.%.

Acknowledgments

The authors would like to thank the support of the National Nature Science Foundation of China (51204073). The National Nature Science Foundation of Guangdong province (2021A1515011728).

References

[1] Jones L C, Llewellyn R J. Sliding abrasion resistance assessment of metallic materials for elevated temperature mineral processing conditions[J]. Wear, 2009, 267(11): 2010.
[2] Aldrich C. Consumption of steel grinding media in mills–A review[J]. Minerals Engineering, 2013, 49: 77.
[3] Bedolla-Jacuinde A, Rainforth M W, Mejia I. The role of silicon in the solidification of high-Cr cast irons[J]. Metallurgical and Materials Transactions A, 2013, 44(2): 856.
[4] Lai J P, Pan Q L, Sun Y W, et al. Effect of Si content on the microstructure and wear resistance of high chromium cast iron[J]. Isij International, 2018: ISIJINT-2018-099.
[5] Lai J P, Pan Q L, Peng H J, et al. Effects of Si on the microstructures and mechanical properties of high-chromium cast iron[J]. Journal of Materials Engineering and Performance, 2016, 25(11): 4617.