Study on the Wear Resistance of Sinter Alloying Steel by Deep Cryogenic Treatment

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Abstract

Sintered alloy steel powder with four different hardenability of FN0200, FN0208, FD0408, and FLNC4808 are applied to form the sintered alloy steel. The sintered alloy steel, being cooled down to room temperature, is further soaked in -196℃ liquid nitrogen for 4hrs deep cryogenic treatment.

With deep cryogenic treatment, the retained austenite in the sintered alloy steel would change the phase and become martensite, and the apparent hardness of sintered alloy steel would be enhanced. Further analyzing the effect of deep cryogenic treatment on the wear resistance of sintered alloy steel, the wear resistance would be improved when the apparent hardness of sintered alloy steel is enhanced. However, the deep cryogenic treatment would change the sintered alloy steel microstructures because of distinct hardenability. Such research findings show the significant effect of deep cryogenic treatment on the sintered alloy steel with high hardenability, where the best hardness and wear resistance could be acquired from FLNC4808 sintered alloy steel through the deep cryogenic treatment.

Keywords: sintered alloy steel, deep cryogenic treatment, hardenability, wear resistance

1. Introduction

Research on sub-zero treatment actually has been done in the early 20th century to change the structure and function of steel by lower than freezing point. In 1937, A. P. Gulyaev [1] first researched sub-zero treatment for high-speed steel and proposed the theory of sub-zero down to -80℃. So far, it is known that deep cryogenic treatment (-196℃) could enhance the ratio of martensite and reduce austenite residue to improve the wear resistance of steel. Deep cryogenic treatment is also broadly used for machinery industry internationally to enhance the wear resistance of ferrous products, such as die steel [2], powder high-speed steel [3], and cast iron [4], and the performance of non-ferrous products, like magnalium [5].

Nevertheless, deep cryogenic treatment has not been applied to the research on sintered alloy steel. This study therefore intends to discuss the effects of deep cryogenic treatment on the mechanical properties and wear performance of sintered alloy steel.

2. Method

Sintered alloy steel with four different multiplying factors of FN0200 (Fe- 1.2Cu- 2.5Ni- 0.3C), FN0208 (Fe- 1.2Cu- 2.5Ni- 0.9C), FD0408 (Fe- 1.5Cu- 4.0Ni- 0.5Mo- 0.9C), and FLNC4808 (Fe- 2.0Cu- 2.7Ni- 1.25Mo- 0.2Mn- 0.9C) is utilized in this study. The alloy contents are shown in Table 1.

The as-sintered steel are further proceeded deep cryogenic treatment from room temperature down to cryogenic temperature -196℃ with 0.3℃/min for 4hr and then slowly increased to room temperature with 0.3℃/min. Finally, sintering sintered alloy steel and cryogenically treated sintered steel are tempered with 180℃ for 1hr to remove residual stress caused by phase change.

Furthermore, the mechanical property is experimented. The above test pieces are measured the surface Vickers micro hardness (Hv_1) with 1Kg load.

The prepared φ5 cylinder wears test pieces and placed on the Pin-on-disc wear test platform,

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Fig. 1. The wear test platform rotates an SKD11 disc with the speed 60 rpm, and the wear test piece is placed 47.5 mm away from the disc center shaft, while a 2 Kg load is loaded on top of the wear test piece. Each test piece is proceeded the wear test of the wear distance 15,000m, and the measured wear weight loss is calculated the wear coefficient of the test piece with the following equation.

$$K = \frac{\mathrm{m}}{\rho \mathrm{F} \iota}\left[\frac{mm^3}{\mathrm{Nm}}\right] \quad (1)$$

where K: wear coefficient;
m: wear amount, g;
ρ: density, g/mm^3;
F: positive load on wear test piece, N;
t: wear distance, m.

Table 1 Sintered alloy steel contents

Material	Elements (wt. %)						Multiplying factor
	C	Cu	Ni	Mo	Mn	Fe	
FN0200	0.3	1.2	2.5	-	-	Bal.	3.3
FN0208	0.9	1.2	2.5	-	-	Bal.	3.7
FD0408	0.9	1.5	4.0	0.5	-	Bal.	13.5
FLNC4808	0.9	2.0	2.7	1.25	0.2	Bal.	40.4

MPIF Standard 35: FN0200 (0-0.3%C, 1.3-1.7%Cu, 1-3%Ni, Bal. Fe)
FN0208 (0.6-0.9%C, 1.3-1.7%Cu, 1-3%Ni, Bal. Fe)
FD0408 (0.6-0.9%C, 1.3-1.7%Cu, 3-5%Ni, 0.4-0.6% Mo, Bal. Fe)
FLNC4808 (0.6-0.9%C, 1-3%Cu, 1-3%Ni, 1.1-1.4% Mo, Bal. Fe)

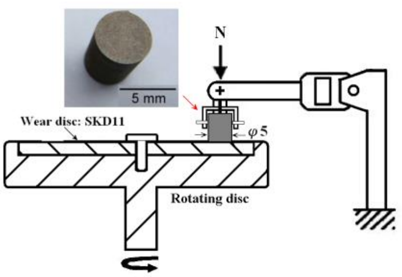

Fig. 1 Pin-on-disc wear test schematic

3. Results and Discussion

3.1. The Hardness of Sintered Alloy Steel

The effects of deep cryogenic treatment on the hardness of sintered alloy steel with different hardenability are further analyzed. The as-sintered steel after deep cryogenic treatment, where the apparent hardness could be improved by deep cryogenic treatment, regardless of the hardenability. Sintered alloy steel with distinct hardenability would enhance the apparent hardness with increasing hardenability, revealing that sintered alloy steel would be hardened with deep cryogenic treatment. Especially, most of the austenite structure in high carbon high hardenability alloy steel (FD0408) is changed into martensite and the austenite residue is dropped down to the lowest that the apparent hardness is increased from Hv_1 516 to Hv_1 733. The improvement of wear resistance could enhance sintered alloy steel parts to a higher level.

3.2. The Wear Resistance of Sintered Alloy Steel

The sintered alloy steel wear test pieces with different hardenability are placed on the Pin-on-disc wear test platform for the 15,000m wear test to measure the wear weight. The sintering FN0200 alloy steel with the lowest hardenability is worn the weight 0.0547g with 15,000m, while the sintering FLNC4808 alloy steel with the highest hardenability is merely worn 0.0014g with 15,000m; after deep cryogenic treatment, FLNC4808 further drops down to 0.0009g, Fig. 2. The result explains that sintered alloy steel could be improved the wear resistance with deep cryogenic treatment.

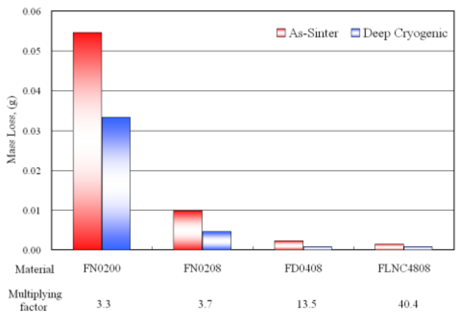

Fig. 2 Wear weight of sintered alloy steel wear test

Substituting the density (ρ), wear distance (t), test piece wear weight (m), and wear load (F) of the sintered alloy steel test pieces for Eq. (1) to analyze the wear coefficient, the results are shown in Fig. 3.

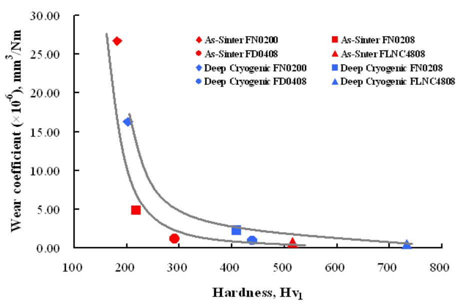

Fig. 3 Comparisons of wear coefficient of sintering sintered alloy steel after cryogenic treatment

From the curve in Fig. 3, the sintered alloy steel with deep cryogenic treatment could effectively reduce the surface wear of sintered alloy steel parts. High carbon high hardenability sintered alloy steel (FLNC4808) with deep cryogenic treatment could further enhance the wear coefficient from K=0.72($\times 10^{-6}$ mm^3/Nm) to K=0.46($\times 10^{-6}$ mm^3/Nm), and the metallurgical structure is mostly changed into martensite.

Among sintered alloy steel with distinct hardenability, the wear coefficient (K=0.46$\times 10^{-6}$ mm^3/Nm) of FLNC4808 sintered alloy steel with deep cryogenic treatment outperforms the wear coefficient (K=2.25$\times 10^{-6}$ mm^3/Nm) of FN0208 sintered alloy steel with deep cryogenic treatment, and even better than FD0408 sintered alloy steel (K=0.93$\times 10^{-6}$ mm^3/Nm). The result presents that among sintered alloy steel with different hardenability, FLNC4808 sintered alloy steel with deep cryogenic treatment could acquire the best wear resistance and effectively reduce the surface wear of sintered alloy steel parts.

4. Conclusions

(1) As-sintered alloy steel with higher hardenability would enhance the apparent hardness as austenite changes the phase into martensit.

(2) Austenite of sintered alloy steel with deep cryogenic treatment would change into martensite. Such a change enhances the structure apparent hardness.

(3) Regarding the hardness performance and wear resistance of sintered alloy steel with distinct hardenability, high hardenability alloy steel (FLNC4808) with the hardenability above 40 presents the best hardness performance and wear resistance combination.

(4) FLNC4808 sintered alloy steel with deep cryogenic treatment presents the best wear resistance, which is suitable for machine parts requiring high wear resistance.

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References

[1] A. P. Gulyaev, “Improved methods of heat treating high speed steels to improve the cutting properties,” Metallurgy, vol. 12, pp. 65-70, 1937.

[2] B. Podgornik, et. al., “Improving tribological properties of tool steels through combination of deep-cryogenic treatment and plasma nitriding,” Wear, vol. 288, pp. 88-93, 2012.

[3] V. Leskovšek and B. Podgornik, “Vacuum heat treatment, deep cryogenic treatment and simultaneous pulse plasma nitriding and tempering of P/M S390MC steel,” Materials Science and Engineering: A, vol. 531, pp. 119-129, 2012.

[4] T. Slatter, R. Lewis, and A. H. Jones, “The influence of cryogenic processing on wear on the impact wear resistance of low carbon steel and lamellar graphite cast iron,” Wear, vol. 271, pp. 1481-1489, 2011.

[5] K. M. Asl, et. al., “Effect of deep cryogenic treatment on microstructure, creep and wear behaviors of AZ91 magnesium alloy,” Materials Science and Engineering: A, vol. 523, pp. 27-31, 2009.