RESEARCH NOTE

THE EFFECT OF EPSILON PHASE ON THE FRICTION AND WEAR OF NITRIDED DIE STEELS

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Abstract In this paper, the wear resistance and antifriction of epsilon phase layer and diffusion layer of gas nitrided D2 steel and M2 steel have been studied. The changes in wear mechnism of epsilon phase under the load from 20N to 200N are analysed. When the load is lighter than 100N, it is mainly oxidizing wear on friction surface. The adhesion, peeling off and abrasive wear appear on friction surface while the load is heavier than 150N. The epsilon phase on nitrided D2 steel surface can reduce oxidizing wear and adhesion, and delay abrasive wear. The friction coefficient of D2 steel can be reduced by 19%, and the wear resistance can be increased 200% to 300% by the epsilon phase layer on nitrided surface.

Key Words Die Steel, Nitriding, Wear, Antifriction

چکیده در این تحقیق، مقاومت سایشی و ضد اصطکاکی لایه فاز اپسیلن و لایه نفوذی فولادهای نیتریده D2 و M2 بررسی شده است. تغییرات مکانیزم سایش فاز اپسیلن تحت نیروی از ۲۰ تا ۲۰۰ نیوتن تحلیل شده است. وقتی که بیش از ۱۵۰ نیوتن نیرو اعمال می شود، چسبندگی، کندگی و سایش فرسایشی روی سطح اصطکاک ظاهر می شود. فاز اپسیلن روی سطح فولاد نیتریده D2 می‌تواند سایش اکسید کننده و چسبندگی را کاهش داده و سایش فرسایش را به تأخیر اندازد. وجود لایه فاز اپسیلن روی سطح نیتریده می‌تواند ضریب اصطکاک فولاد D2 را ۱۹ درصد کاهش داده و مقاومت سایش را ۲۰۰ تا ۳۰۰ درصد بیافزاید.

INTRODUCTION

Previous research shows that anti-adhesion and wear resistance of dies and punchs can be improved by nitriding [1, 2]. The various microstructures of nitrided layers were presented by different processes or on varied steels. Some of them contain an epsilon phase layer on their surface, but others do not. They may only have a diffusion layer [3]. The difference of microstructure affects the tribological characters and wear resistance significantly. Some scholars have reported that epsilon phase improves the wear resistance and anti-adhesion greatly [4]. Others have pointed out that the wear resistance of nitrided parts mainly depends on the diffusion layer [5]. Therefore, the authors of this paper have studied and compared the anti-friction and wear resistance for two kinds of nitrided die steel with or without epsilon phase in thier nitrided layers.

EXPERIMENTAL PROCEDURE

The chemical compositions of test steels and their heat treatment processes and Rockwell hardness before nitriding are listed in Table 1. The roughness of samples after grounding is 0.8 μm. Then the samples are nitrided in a gas nitriding furnace of 8KW with NH_3 gas. The nitriding samples are hold at 520°C -540°C for 6h. The flow rate of NH_3 gas passing into the furnace is 1/7 of the chamber capacity. The dissociation of NH_3 is about 40%-60%. A series of hardness is measured from surface to different depths by a Vickers hardness with 50g load. The depth of the nitrided layer depends on the distance from the surface to the location where hardness is 50HV higher than the one of the core. The thickness of the epsilon phase layer is measured by a microscope with the microscale. The microstructures of nitrided layer for two kinds of steel are shown in Figure 1. The surface hardness and the depth of nitrided layer are list in Table 2. The bright white layer on the surface of nitrided D2 steel is identified as epsilon phase by an examination of X-ray diffraction.

The friction and wear tests are carried out on a ball-disk type tester. A hardened steel ball of 10mm diameter slips to and from on the surface of nitrided samples, as shown in Figure 2. The dimensions of nitrided samples are 8mm high and 24mm diameter. The opposite balls made of 52100 steel are quenched from 840°C, tempered at 180°C, and have a hardness of 60HRC. The balls are ground before being used. The original surface roughness is all 0.8μm. The frequency of the ball sliding is 10Hz, the stroke is 2mm, and the sliding speed is about 2.4m/min. All of the tests are carried out in the atmospheric environment and a temperature of about 22°C, with both abrasive and lubricant. The friction coefficients are automatically recorded by a computer system. The

TABLE 1. The Chemical Compositions of Steels, Pre-treatment Process and Rockwell Hardness Before Nitriding.

Steel	Main elements content (wt%)							Process	Hardness (HRC)
	C	Si	Mn	Cr	Mo	W	V		
D2	1.47	0.15	0.26	11.73	0.49	-	0.20	Quenching from 1110°C, tempering at 540°C twice	62
M2	0.86	0.26	0.30	4.17	4.80	5.84	1.92	Quenching from 1150°C, tempering at 560°C twice	61-62

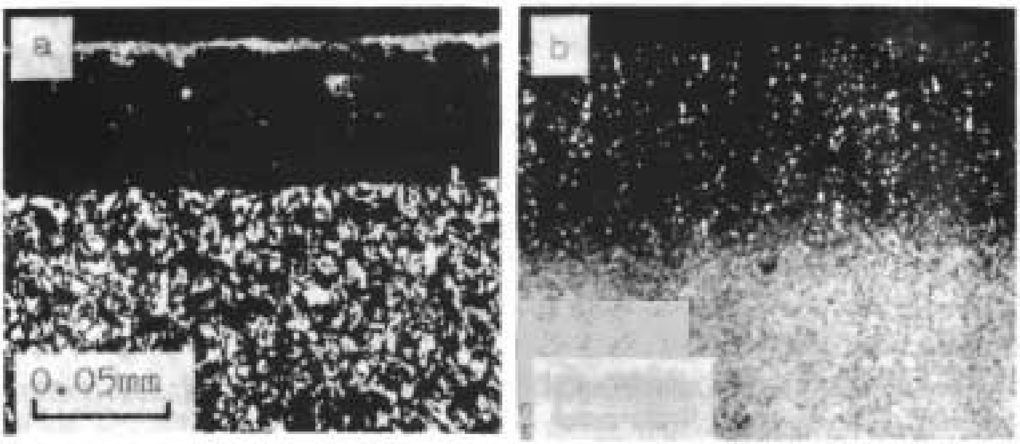

Figure 1. The microstructure of two kingds of nitrided steels (etched by nital, **a**-D2 steel, **b**-M2 steel).

TABLE 2. The Depth of Nitrided Layer and Hardness of Steel.

Steel	Depth of nitrided layer (mm)		Hardness (HV 0.1)	
	Epsilon phase	Diffusion layer	Surface	Core
D2	0.003	0.09	1042	775
M2	0.000	0.12	1130	750

wear of disks is measured by a surface profilometer. The worn surface morphology of disks is observed by a scanning electronic microscope.

RESULTS AND DISCUSSION

Friction Coefficients

The dry friction coefficient of test steels against hardened 52100 steel under different loads is shown in Figure 3. When the load is lighter than 100N, the coefficient decreases as the load increases because of the effect of oxide and convexity on the surface. When the load is heavier than 100N, the surface contacted between the ball and the plate has been pressed closely and it is "the true friction surface". The coefficient will not change with the load increase. It is very clear from Figure 3 that the epsilon phase layer on the surface of nitrided steel decreases the friction significantly. When the load is heavier than 100N, the friction coefficient of nitrided D2 steel with an epsilon phase layer on its surface becomes 0.30. It reduces to about 19% less than that of unnitrided D2 steel. The coefficient of the latter is 0.37. While the friction coefficient of nitrided M2 steel without epsilon phase on its surface only decreases to 8.3% less than that of unnitrided one, it becomes 0.33 from 0.36. It is shown that epsilon phase layer can decrease the friction coefficient to about 10% less than that of nitrided diffusion layer.

Wear Resistance

The wear loss of the two kinds of steel after sliding wear 72m under different loads is listed in Figure 4. The core hardness of D2 steel and M2 steel after nitriding is 61HRC-62HRC. They have the same deformation resistance. The difference between two kinds of steel is that there is an epsilon phase layer on the top of diffusion layer for nitrided D2 steel, and

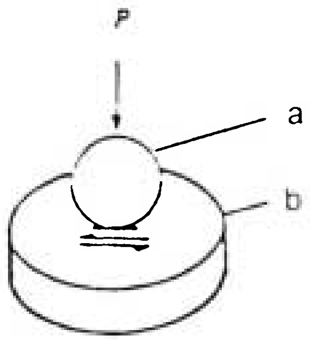

Figure 2. The simple of wear test (a-nitrided sample, b-opposite hardened steel ball).

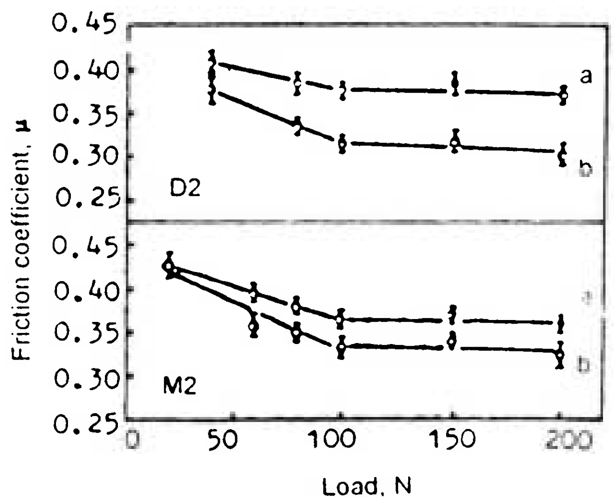

Figure 3. The friction coefficient of stee[illegible]s load (a-unnitrided, b-nitrided).

no epsilon phase for nitrided M2. Both kinds of steel improve the wear resistance by nitriding, but the mechanism is different. Using the formula $(V_U-V_N)/V_N$ to calculate the improvement of wear resistance, the results in Figure 5 are obtained. In the above formula, V_U is the wear loss of unnitrided sample, V_N is the wear loss of nitrided one. It is obvious in Figure 5 that the epsilon phase layer has a better wear resistance than the diffusion layer. Under a lower load of 40N, the wear resistance of epsilon phase layer is 300% higher than that of unnitrided sample. When the load is increased to 200N, the epsilon phase can improve the wear resistance over 200% than unnitrided sample, while the wear resistance of the sample with diffusion layer (nitrided M2 steel) under the same load is only improved by 50% or 88% compared with that of unnitrided sample. Therefore, the wear resistance of the epsilon phase layer is about 160% to 267% of the diffusion layer.

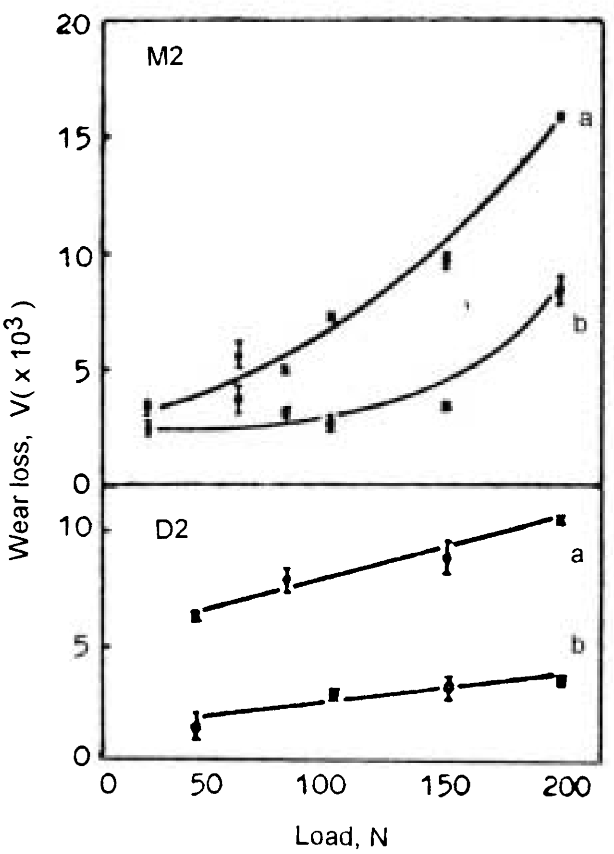

Figure 4. The effect of nitriding on the wear resistance of steels after sliding wear 72 m (a - unnitrided, b- nitrided.)

The Wear Mechanism

The wear morphology observed by SEM and the distribution of oxygen measured by WDX on the worn surface are shown in Figure 6. The results show that the wear is composed of oxidizing, adhering, fatigue and abrasive wear. Under the lower load, it is mainly the oxidizing wear. The mechanism in improving wear resistance by epsilon phase is due to its high oxidation resistance. When the load becomes heavy, the adhesion and peeling off appear on the wear surface. Then the mechanism in improving wear resistance by epsilon phase contributes to the effect of lubricant and antiadhesion which is related to the hexagonal closepacked construction of epsilon phase. So the epsilon phase can prolong oxidizing wear period in a larger load range than the diffusion layer and delay the peel off and abrasive wear. It is a good way to improve the service life of dies making an epsilon phase layer on the surface of dies by gas nitriding.

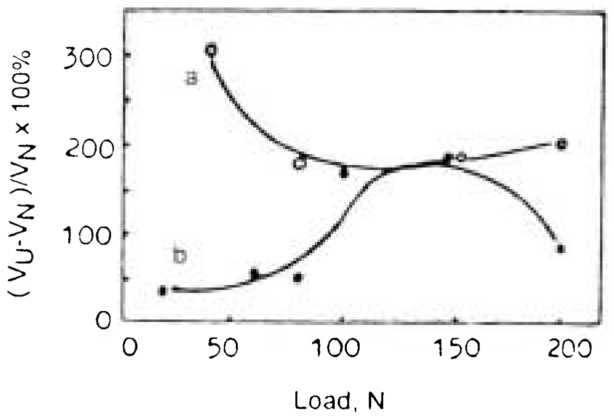

Figure 5. The level of nitrided layer to improve the wear resistance, a-epsilon phase layer (nitrided D2 steel), b- diffusion layer (nitrided M2 steel).

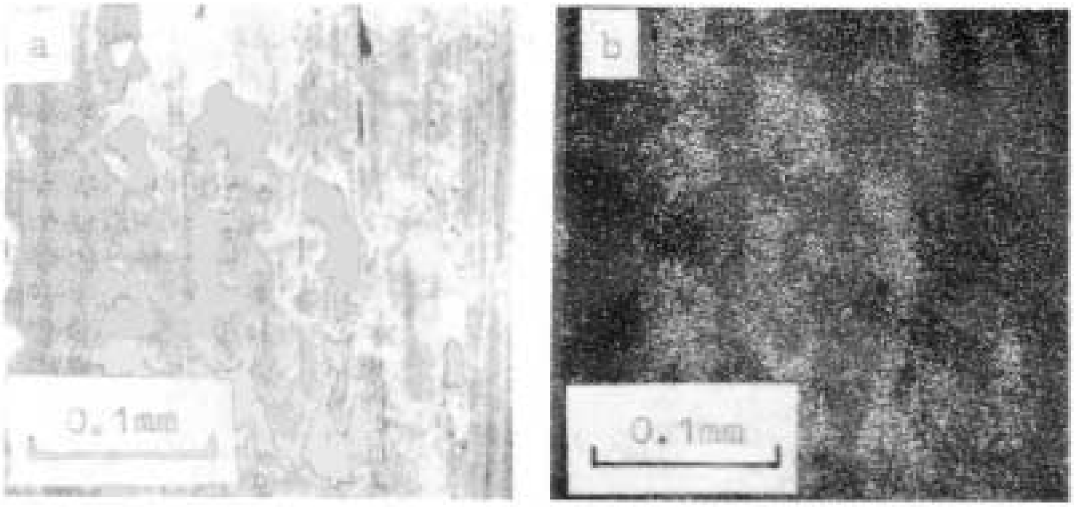

Figure 6. The adhesion morphology (**a**, by SEM) and the distribution of oxygen on worn surface (**b**, by WDX).

CONCLUSIONS

1) The epsilon phase formed on the surface of nitrided high hardness die steels is excellent to reduce the friction. Under a heavier load of 100N, the friction coefficient of epsilon phase when the nitrided die steel rubbed with the hardened steel is decreased by 19% of that of unnitrided, and decreased by 10% of that diffusion layer.

2) The effect in improving wear resistance of epsilon phase for the nitrided die steels will become stronger as the load increases. Under 200N load, the wear resistance of epsilon phase layer is 200% higher than that of unnitrided surface, and is 60% higher than that of diffusion layer.

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