

Wear behavior of AISI D2 steel by enhanced ion nitriding with atomic attrition

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ABSTRACT

An experimental study was performed to investigate the effect of atomic attrition on wear behavior of AISI D2 steel. Wear tests were conducted under three different loads (5, 10, and 20 N) and sliding speeds (100, 200, and 500 rpm), using ball-on-disk type tester and SiC ball. After wear test, the specimen nitrided with ion bombardment showed superior wear behavior. The enhanced hardness by ion bombardment could have a beneficial effect on increased wear resistance. In addition, a wider and more adhesive oxide layer formed on the worn surface of ion-bombarded specimen, because of the rougher structure on the surface by ion bombardment, could lead the surface to withstand wear for longer duration time, acting as a protective layer.

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1. Introduction

It is generally known that surface hardness has a strong correlation with wear resistance when the surfaces come into contact with each other, causing friction and wear; that is, there is an inverse relationship between surface hardness and wear rate. To improve the surface properties and expand the working life of engineered materials, several processes are widely used in industry such as nitriding, carburizing, nitro-carburizing, etc. Many studies on the tribological behavior related to those surface-hardening treatments have been performed over the past few decades [1–8].

Among several surface treatments for the improved tribological behavior of engineered parts, nitriding is one of the most useful and frequently used processes in industry because it is well-known that it shows beneficial characteristics such as less distortion at low process temperatures and higher surface hardness resulting from the presence of a compound layer on the topmost surface, although it shows shallower case depth. Devi's group [2] reported the wear mechanism of several nitrided tool steels, H13, D2, and L7'. The mechanism changed from adhesion to delamination and abrasive wear. Yang et al. [5] studied the effect of nitriding on the tribological behavior of 2Cr13 steel under air and vacuum atmospheres. Compared to the unnitrided specimen, the nitrided

specimen showed superior tribological behavior under both air and vacuum conditions, indicating oxidative wear and adhesion wear under air and vacuum conditions, respectively.

Meanwhile, enhanced surface hardening by ion bombardment was recently reported by Abranonis and Moller [9]. It has also been reported that the surface hardness and N mobility increased by argon bombardment after the nitriding process, suggesting a quasi-particle-enhanced mobility. Cho et al. [10] also showed that two-step nitriding including argon bombardment could result in higher surface hardness than could be accomplished with conventionally ion-nitrided specimens. They found that the surface-hardening factors are refined grains, higher nitrogen concentration, and higher fraction of chromium nitrides in the surface region during two-step nitriding accompanied by ion bombardment.

As illustrated above, nitriding is widely used to expand the working life of engineered materials, and many studies have been conducted on the nitriding process. Furthermore, it has also been reported that ion bombardment enhances the mechanical properties of engineered materials. However, there are few studies on the effect of ion bombardment on the wear behavior of engineered materials, even though ion nitriding is widely used in industry and ion bombardment is an easy process to utilize during the ion-nitriding process.

The present study investigated the effect of ion bombardment on the wear behavior of ion-nitrided engineered materials. AISI D2 steel was selected as the experimental specimen because it is most frequently subjected to the nitriding process in order to prolong its working life. Three types of specimen were prepared for comparison:

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an industrially quenched and tempered base material, an ion-nitrided material without ion bombardment, and an ion-nitrided specimen with ion bombardment.

2. Experimental procedure

An industrially quenched and tempered AISI D2 steel rod was used as the base material. The steel had the following chemical composition (wt%): 1.52 C, 12.8Cr, 0.99Mo, 0.38 V, 0.53Mn, 0.4Si, 0.04 P, and 0.02 S. The core hardness of the base material was approximately 670 HV0.1 and it was processed to a shape of $\varnothing 30 \times 10$ mm. Prior to the ion-nitriding process, all specimens were ground with 200, 600, 1200, and 2000 grade sand paper. All specimens were in turn placed in an ultrasonicator bath containing ethanol and cleaned for 3 min.

Table 1

Specimen nomenclature.

Base material : Industrially quenched and tempered	
Specimen A	: Single ion nitriding for 480 min (1 step: N_2 and H_2)
Specimen B	: Two step ion nitriding for 480 min (1st step for 120 min: $N_2 + H_2$, 2nd step for 360 min: $N_2 + Ar$)

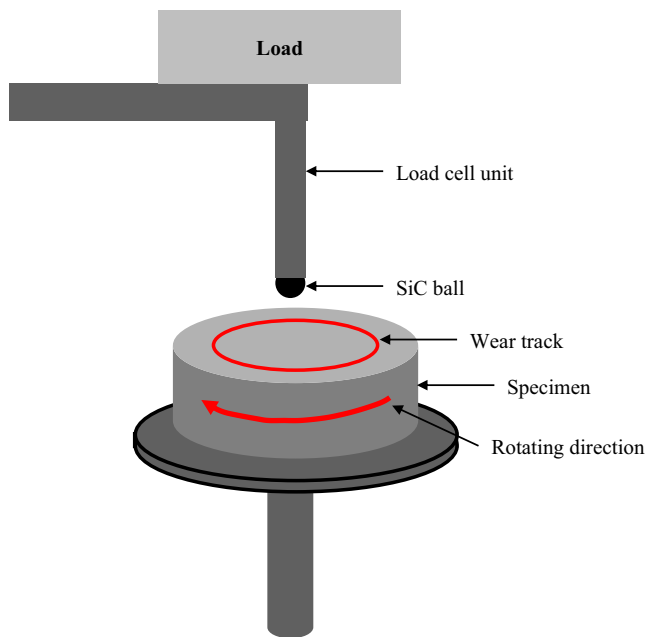


Fig. 1. Schematic drawing of ball-on-disk type wear tester.

Two kinds of ion nitriding were conducted, as listed in Table 1. A mixture of hydrogen and nitrogen was used for 480 min on Specimen A and a mixture of argon and nitrogen for 360 min followed by a mixture of hydrogen and nitrogen for 120 min was used on Specimen B. More detailed parameters about the ion-nitriding process are illustrated in [10].

Wear tests were performed by using a ball-on-disk type tribometer, as illustrated in Fig. 1. Specimens were placed on a clockwise-rotating stage, while a SiC ball specimen with a diameter of 5.953 mm and a hardness of 2100 HV was loaded in a load arm. The applied normal loads were 5, 10, and 20 N (1.3, 1.7, and 2.1 GPa in the Hertzian maximum stress) and various sliding speeds of 100, 200, and 500 rpm (0.05, 0.1, and 0.26 m/s, respectively) were chosen at a radius of 10 mm under ambient conditions of approximately 290 K (17 °C) and approximately $20 \pm 10\%$ humidity. The total sliding distance was chosen to be 10,000 cycles, and an additional wear test of 2000, 5000 cycles in total sliding distance was carried out to observe the wear mechanism during the wear test. All tests were conducted three times and averaged value was reported in this study.

All nitrided specimens were characterized by using a micro-Vickers hardness tester (Future Tech FM-7) with a load of 100 g and a dwell time of 10 s and optical microscopy (OM, Olympus BX51-33MU). All the specimens were cleaned after the wear test in the ultrasonicator containing ethanol and the wear mechanism was observed by scanning electron microscopy (SEM, QUANTA 200F-EDAX) with an energy dispersive X-ray spectrometer (EDS). Atomic force microscopy (AFM, Pacific Nanotechnology NANO R) was utilized to investigate the surface topology of the specimens.

3. Results

The cross-sectional microstructures of the base material and Specimens A and B are shown in Fig. 2(a), (b), and (c), respectively. The microstructure of the base material shows tempered martensite induced by the industrial quenching and tempering process and small coarse particles all over the base material. For both nitrided specimens, a chemically attached region was commonly observed near the surface region and a compound layer several micrometers in thickness on the top surface.

Fig. 3 shows the hardness profile of the specimens from the top surface to the core. The hardness of the base material was approximately 670 HV, which was caused by the industrial quenching and tempering process. Specimen A, subjected to a single ion-nitriding step, shows a surface hardness of approximately 1250 HV and the hardness decreased as the hardness measuring point moved toward the core. The case depth of Specimen A was approximately 60 μm from the top surface. The hardness of Specimen B was about 1500 HV at the surface, which was approximately 250 HV higher than that of Specimen A. The case depth was about the same as that of Specimen

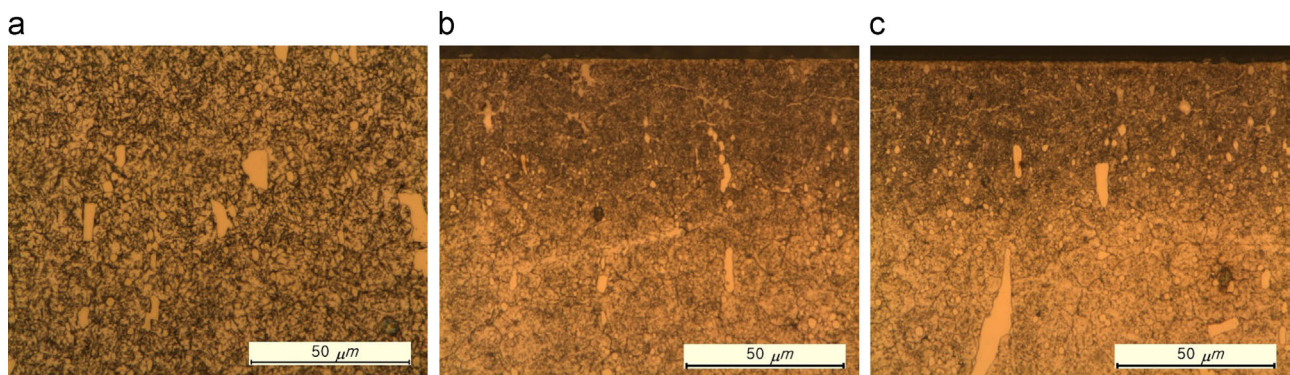


Fig. 2. Crossectional microstructure of (a) base material, (b) ion nitrided specimen without ion bombardment and (c) with ion bombardment for 8 h.

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