The effects of plasma nitriding process parameters on the wear characteristics of AISI M2 tool steel

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Received 6 December 1999; accepted 20 June 2000

The main aim of this work is to evaluate the effects of the plasma nitriding process on AISI M2 tool steel. In previous work, treatment time and temperature were varied to identify the treatment conditions for good wear behaviour. In the present work, the treatment time was fixed while temperature and gas pressure were varied. Samples were characterised by glow discharge optical spectroscopy, scanning electron microscopy, X-ray diffraction, surface microhardness and wear test. The specimens nitrided at 400 and 900 Pa showed the best wear performance, which is possibly due to reduction of the friction coefficient and the low adhesive wear observed. Samples processed at 200 Pa showed spalling during the wear test, indicating a brittle surface.

Keywords: plasma nitriding, wear, tool steel

1. Introduction

Plasma nitriding is a plasma-activated thermochemical diffusion process for the surface hardening of metallic materials such as steels, titanium [1] and aluminium alloys [2]. Improvements in friction coefficient, wear and fatigue resistance are produced on materials due to the high surface hardness of nitried layers.

The plasma nitriding process is accomplished in a vacuum chamber where the specimen is connected to a cathode [3]. A high voltage (about 300–1000 V) is applied between the cathode and the vessel, which works as an anode, and the gas pressure varies from about 100 to 1300 Pa (1–13 mbar). Under these conditions, an abnormal glow discharge that covers the specimen is obtained. The ion nitriding process normally is preceded by a cleaning and pre-heating stage that is carried out under an atmosphere of hydrogen. Then, the addition of the nitrogen initiates and sustains the nitriding action [4].

The positive nitrogen ions in the glow discharge are attracted towards the negatively charged work pieces. They impinge upon these surfaces and heat up the pieces to the required diffusion temperature. Hardening is accomplished due to the formation of diffusion and compound layers. The diffusion layer consists of very fine nitride particles [4], where the nitrogen content decreases towards the core. The compound layer, which is also called “white layer”, consists of iron nitrides, the epsilon phase (\(\varepsilon\)-Fe_{2-3}N) and/or the gamma prime phase (\(\gamma'\)-Fe_{2}N), whose thickness is generally less than that of the epsilon phase.

Compared with conventional nitriding processes, plasma nitriding offers additional advantages, such as reduced treatment time, reduced distortion, demonstrates improved white layer control, as the properties of the nitried layer can be adjusted by controlling the process parameters [4,5], and it is environmentally friendly.

Plasma nitriding is carried out on high-speed steel (HSS) tools to increase the wear resistance of the cutting edge and to reduce the adhesion of the work material to the tool. The nitrided surface enriched in nitrogen has better slip properties that facilitate easier cutting, resulting in operation at lower temperatures [6]. Moreover, the mechanical properties improvements on the specimen surface, such as fatigue and wear resistance, friction coefficient reduction and high hardness, do not result in bulk toughness loss.

The purpose of the present work is to enhance the wear resistance of AISI M2 tool steel. This study was carried out in two stages. In the first one, reported by Tier et al. [6], different times and temperatures were analysed. The best wear results were observed for samples that were plasma nitrided at 450 and 500 °C for 60 min. In such cases, the nitried layer was adequate to avoid the adhesion and material loss from the counterpart, with sufficient toughness to avoid spalling [6]. In the second stage, presented in this paper, the treatment time was fixed while temperature and gas pressure were varied. The gas pressure, which has already been studied by some authors [7–10], is related to important factors, such as ionisation and nitriding efficiency, plasma distribution, hole penetration, general coverage uniformity and effects on surface layer growth. According to Russet [8], the application of plasma nitriding technology for a certain component involves, besides other considerations, the establishment of the optimum working pressure. However, there is insufficient information in the literature to explain the precise mechanism by which gas pressure affects the plasma nitriding process.
2. Experimental

The material used in this investigation was the AISI M2 tool steel heat treated (quenched and tempered) to a hardness of 835 HV (65.5 HRC). The chemical composition of the high-speed steel AISI M2 is shown in table 1.

Cylindrical samples of 16 mm in diameter and 12 mm thickness were prepared as follows: For examination of cross section, samples were ground to 1200 grade SiC paper and polished to 1 µm diamond paste, and those submitted to the wear tests were only ground to 400 grade SiC paper. The samples were then pre-cleaned using chemical solvents and the final cleaning step was performed in the chamber by sputtering with hydrogen at 200 Pa for as long as was needed to reach the required temperature.

The plasma nitriding process was carried out in a 40 kW Klöckner plasma nitriding unit under a discharge containing 25% nitrogen and 75% hydrogen. The voltage applied during the experiment was between 330 and 620 V.

In previous work, reported by Tier et al. [6], samples were plasma nitrided at 400 Pa (4 mbar), at temperatures of 450 and 500 °C for 18, 30 and 60 min. Since the best wear resistance was observed for samples processed for 60 min, in this investigation plasma nitriding was performed at 450 and 500 °C and at 200, 400 and 900 Pa for 60 min.

Glow discharge optical spectrometry (GDOS) was used to determine the nitrogen concentration profile through the nitrided layer. The analysis was carried out in a Leco GDS-750QPD equipment.

The structure of the nitried compound layer was investigated using X-ray diffraction analysis in a Philips PW 1050 diffractometer. Specimens were scanned through 2θ values ranging from 50° to 160° in 0.05° steps using Cr Kα radiation.

Wear tests were performed employing an Amsler machine using a disc-against-flat-surface-type test, without lubrication, and the load was set at 80 kg for 300 revolutions and 20 m/min speed. The nitried steel was the flat surface in the test and the disc (counterpart – 50 mm diameter ×10 mm wide) was hardened and tempered to 393 HV (40 HRC) hardness. During the test the torque was measured and the friction coefficient obtained by applying the equation

\[ \mu = \frac{T}{rN}, \]

where \( \mu \) is the friction coefficient, \( T \) is the torque measured, \( N \) is the applied load, and \( r \) is the wheel radius. The

<table>
<thead>
<tr>
<th>Temperature</th>
<th>450 °C</th>
<th>500 °C</th>
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</thead>
<tbody>
<tr>
<td>200 Pa</td>
<td>400 Pa</td>
<td>900 Pa</td>
</tr>
<tr>
<td>Compound layer</td>
<td>–</td>
<td>( \varepsilon )</td>
</tr>
<tr>
<td>Layers depth (µm)</td>
<td>22</td>
<td>36</td>
</tr>
<tr>
<td>Surface hardness (HV 0.2)</td>
<td>1178</td>
<td>1274</td>
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<tr>
<td>Friction coefficient</td>
<td>0.80</td>
<td>0.25</td>
</tr>
<tr>
<td>Scar length (mm)</td>
<td>2.9</td>
<td>1.3</td>
</tr>
<tr>
<td>Wear depth (µm)</td>
<td>42.1</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Table 2
Iron nitrides identified (X-ray analysis), layer depth (GDOS test), surface hardness, friction coefficient, scar length (SEM) and wear depth.

Figure 1. X-ray diffraction patterns showing (a) the absence of compound layer and (b) the characteristic peaks of \( \varepsilon \) (1) and \( \gamma' \) (2) nitrides.