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Technical Report

# The effect of plasma nitriding on the fatigue behavior of DIN 1.2210 cold work tool steel

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ABSTRACT

Plasma nitriding is an important thermo-chemical surface treatment which is widely used in order to enhance the surface hardness, fatigue strength and wear and corrosion resistance of steels. In this research, the effects of plasma nitriding parameters including temperature and time on the microstructure and fatigue strength of quenched and tempered DIN 1.2210 cold work tool steel were investigated. The microstructures of base material and nitrided layer were examined in details by optical microscopy and X-ray diffraction (XRD) analysis. Micro-hardness measurements were used to determine surface hardness and case depth. Fatigue tests were performed using a rotating bending machine. The results indicated that the plasma nitriding process led to a considerable increase in the micro-hardness and fatigue strength values. Furthermore, the maximum fatigue strength was attained after plasma nitriding at 550 °C for 6 h, which increased the fatigue life of the specimens by about 67%. It was also found that the dominant fatigue crack initiation mechanism in the plasma nitrided specimens was subsurface 'fish eye' type crack formation originated from internal nonmetallic inclusions.

## 1. Introduction

Many industrial components, such as automotive parts are subjected to high dynamic loads, wear and corrosion [1,2]. Plasma nitriding, also referred to as ion nitriding or glow discharge, is a thermo-chemical surface treatment that improves fatigue strength, as well as wear and corrosion resistance [3–8]. During the plasma nitriding process, nitrogen diffuses into the metal surface in plasma conditions. This produces a thin hard case with high compressive residual stresses on the surface of steel components. The developed case is comprised of a compound or white layer and a diffusion zone, from the surface inward, respectively [1,9–13]. The aggregate properties of the nitrided steel component are determined by both the core strength and structural characteristics of the compound layer and diffusion zone [14]. The increase in the fatigue strength of steels after plasma nitriding process is attributed to the increase of surface hardness, residual stress distribution and case depth. In the case of the high-cycle fatigue of quenched and tempered materials, fatigue crack usually initiates from the surface while in surface hardened materials crack initiation site shifts from the surface to subsurface. This may be due to the increased hardness and compressive residual stresses of the surface layer, resulting in greater resistance to plastic flow and slip band penetration. Therefore, in the case hardened materials, the cracks tend to originate from internal inclusions at the vicinity of the case/core interface. This, in turn, would enhance the fatigue strength of these materials [3,15–18].

Several researchers have investigated the effect of plasma nitriding treatment on the rotating bending fatigue behavior of a range of steels [3]. However, there is lack of information about the fatigue behavior of quenched and tempered and plasma nitrided DIN 1.2210 steel. This steel is widely used in the production of twist drills and taps, axles and shafts, gear cutters, reamers, countersinks, scraping tools and punches. In the present study, DIN 1.2210 steel has been subjected to the plasma nitriding treatment with $N_2$–$H_2$ gas mixture under different temperature and time conditions, and then its rotating bending fatigue behavior has been evaluated.

## 2. Materials and experimental procedures

### 2.1. Material preparation

The material used in this study was DIN 1.2210 cold work tool steel whose chemical composition (in wt.%) is shown in Table 1. The 9 mm diameter steel bars were supplied in hot rolled conditions. Rotating bending fatigue test specimens were machined on a CNC lathe to the dimensions given in Fig. 1. The fatigue test and cylindrical metallographic specimens were austenitized at 820 °C, for 1 h, quenched in hot oil, and then tempered at 610 °C, for 1 h (Q.T). The experimental steel hardness prior to plasma

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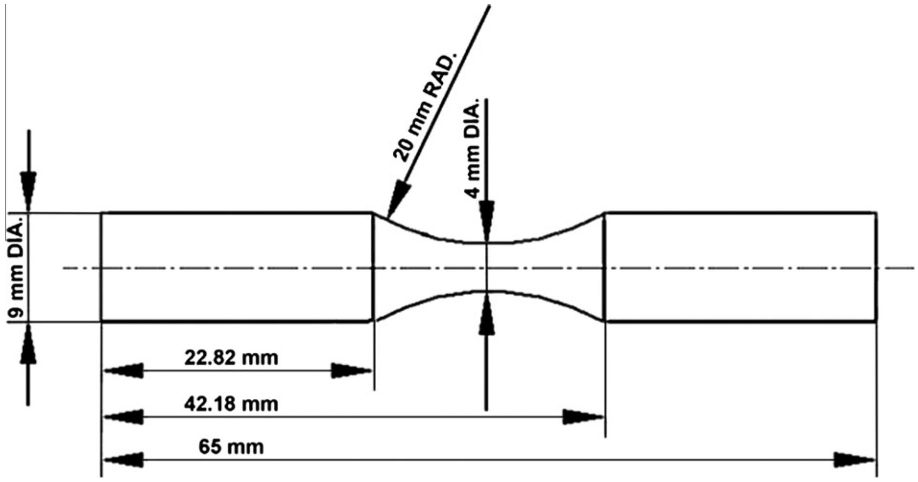

**Fig. 1.** The dimensions of rotating bending fatigue test specimen.

**Table 1**
The chemical composition of experimental steel (wt.%).

| %C | %Si | %Mn | %P | %S | %Cr | %Ni | %V | %Fe |
|---|---|---|---|---|---|---|---|---|
| 1.23 | 0.28 | 0.37 | 0.015 | 0.022 | 0.59 | 0.13 | 0.10 | Bal. |

nitriding process was measured to be 336 HV. To produce a smooth surface, after heat treatment, the surface of the reduced section of the fatigue test specimens was ground using 60, 320, 600, 800, 1200 and 2000 grades emery papers.

### 2.2. Plasma nitriding treatment

Before plasma nitriding (P.N), the specimens were cleaned and degreased in acetone. The plasma nitriding treatment was carried out using a semi-industrial 10 kW furnace operating with DC-pulsed voltage. The specimens were then treated at temperatures of 450 °C and 550 °C for 6 h and 500 °C for 3, 6 and 9 h. A gas mixture consisting of 30% $N_2$ and 70% $H_2$ at the pressure of 5 torr was utilized for all treatments. After plasma nitriding, the specimens were slowly cooled to the room temperature in a vacuum chamber of 0.4 torr, which is shown in Fig. 2.

### 2.3. Microstructure, micro-hardness and phase analysis

After plasma nitriding, the cylindrical specimens were sectioned, mounted and prepared for metallographic studies and micro-hardness measurements. In order to perform metallographic studies using optical microscopy, the treated specimens were etched in 1% Nital solution after being polished. Micro-hardness measurements were also used to determine the case depth. This was carried out on a TIME-HVS-1000 instrument at a constant load of 1.96 N in Vickers scale and loading time of 20 s. According to ISO 4070-1979 standard [2], the effective case depth was defined as the distance below the surface, where the hardness was equal to 400 HV as measured by micro-hardness test. The hardness at 20 μm depth was chosen as surface hardness, so that any possible effects from compound layer would be neglected. In addition, XRD analysis was carried out with a Philips X'pert High score X-ray diffractometer using Cu Kα ($\lambda = 1.5405$ Å) radiation, for detecting phases in the compound layer.

### 2.4. Fatigue test

The room temperature fatigue strength of the specimens was determined by means of a rotating bending fatigue test machine

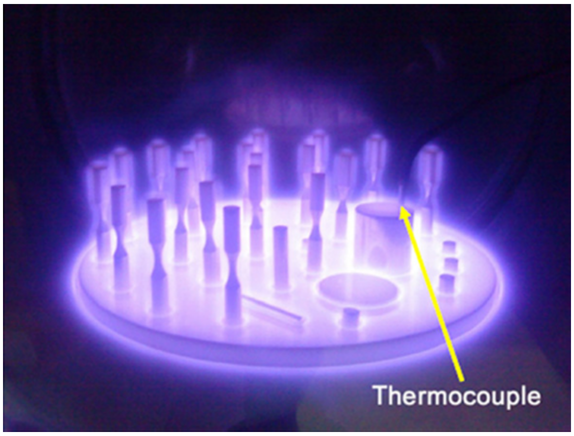

**Fig. 2.** The representation of plasma nitriding chamber and the order of placing specimens.

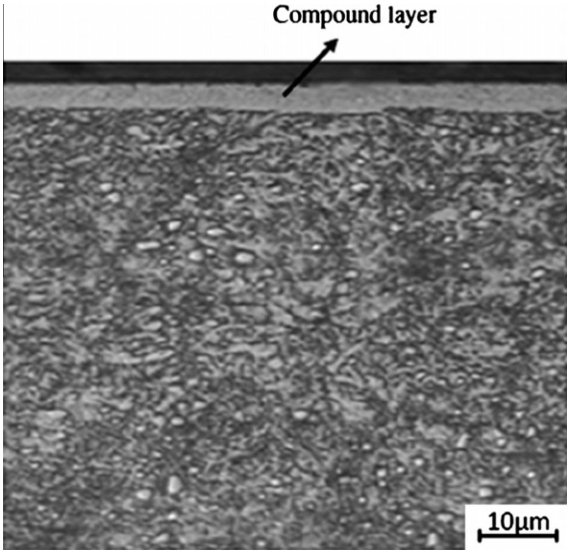

**Fig. 3.** The optical microstructure of plasma nitrided specimen at 500 °C for 3 h.