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Effect of Surface Preparation by Non-Directional Grinding on Properties of AISI D2 Plasma-Nitride Layer

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Abstract. This research studies the properties of plasma-nitride coating on AISI D2 tool steels prepared by non-directional grinding at various finishing. In the manufacturing process, the AISI D2 was machined to size and hardened with a typical hardening process. In addition, its surface was treated with plasma nitriding. Various levels of roughness were produced as well as possible affects on the nitride coating properties. In this study, the following five conditions of grinding were performed on the hardened specimens: 1-μm diamond particle and four SiC grinding papers: P100, P240, P800, and P2500. The surface finishing with at least 0.023-μm roughness value (P800 grinding) provided a plasma-nitride layer with a moderately good hardness profile and a thick nitride layer compared with other finer finishing. This finishing process was also more economical requiring less time and manpower to create than others. Overall, this study suggests that finer surface finishing has a tendency to significantly improve the tool steels hardness profile and hardened depth.

Introduction

This study investigated an industrial process that presents future material process option for manufacturing businesses, and was initiated from the need to understand the relationship between the surface preparation and the properties of plasma-nitride layer. Plasma nitriding, a surface hardening process, is used extensively when compared other conventional nitriding techniques (e.g., gas nitriding, etc.) because it provides a quality protective layer with little or no white brittle compound residue. While plasma nitriding is currently the most common hardening process, little research exists regarding the degree of roughness nor on the sufficient grinding required to meet desired properties of the nitride layer. However, the research that does exist provides a direction for further investigation. In regards to grinding and roughness, Akhatar et al. [1] reported that polished AISI H13 with 0.25-μm diamond contributed to thicker and more uniform gas-nitride layer when compared with AISI H13 with a rough machining. Furthermore, Rocha et al. [2] suggested that AISI M2 surface preparation with 1-μm diamond polishing leads to a higher plasma-nitriding rate producing a thicker nitride layer when compared to grinding and sand-blasting processes. Other preparation techniques, e.g., shot peening [3], and pre-tension [2], were also reported to facilitate the formation of nitride layer. Based on previous research [1,2], this study utilized a non-directional grinding machine, typically used for metallographic sample preparation, with SiC grinding paper, and polycrystalline diamond particle to produce various surface finishing. The surface roughness, thickness of nitride layer, and hardness profile along the cross-sectional area evaluated to determine the performance of the nitride layer.

Experimental procedure

First, fifteen specimens of disc-shape AISI D2 with a diameter of 39.5-mm and thickness of 10-mm were prepared by CNC turning and flat-grinding on its circular sections. Then, every three specimens were subjected to one of five levels of surface finish using the SiC grinding papers (P100, P240, P800, and P2500) and 1-μm diamond particle. Specimens were then processed through a series of non-directional grinding using 5-lbs load automatic metallographic polisher starting from the P-100

grinding paper to the target finishing level. After the non-directional grinding, the materials were hardened using an industrial treatment procedure (two-step heating at 500 ^{o}C and 820 ^{o}C for 30 minute/step, austenitization at 1040 ^{o}C for 60 minute, and double tempering at 520 ^{o}C for 150 minute/cycle). The surface finishing was repeated for each specimen. A surface roughness tester or an Atomic Force Microscopy (AFM) was used to characterize the material roughness depending on the level of surface roughness. Then, specimens were plasma-nitrided at 480 ^{o}C using 30 A and 220 V for 20 hours, and cross-sectioned perpendicular to the prepared surface. Finally, a typical metallographic specimen preparation was performed using a 3%-Nital solution as an etchant. The properties of the plasma-nitride specimens were characterized using optical and scanning electron microscopes, and Vicker hardness tester (100-g load).

Results and discussion

Surface roughness of the five conditions of non-directional grinding was characterized as summarized in Table 1. For the surface roughness tester measurements, the average roughness was calculated from 15 measurements (5 measurements/specimen) with sampling length of 0.25x5 mm according to ASME B46.1-2002. AFM was additionally utilized to characterize specimens prepared by P2500 and 1-µm diamond grinding, since their roughness values exceeds resolution limit of the roughness tester. Example of topography image randomly selected from surface prepared by 1-µm diamond grinding is shown in Figure 1. Smaller grinding particles produced finer surfaces.

Table 1 Roughness of specimen prepared by various finishing

Finishing condition	Average roughness (µm)	Characterization technique
P100	0.12±0.01	Surface roughness tester
P240	0.069±0.007	Surface roughness tester
P800	0.023±0.003	Surface roughness tester
P2500	0.008	AFM
1-µm diamond	0.005	AFM

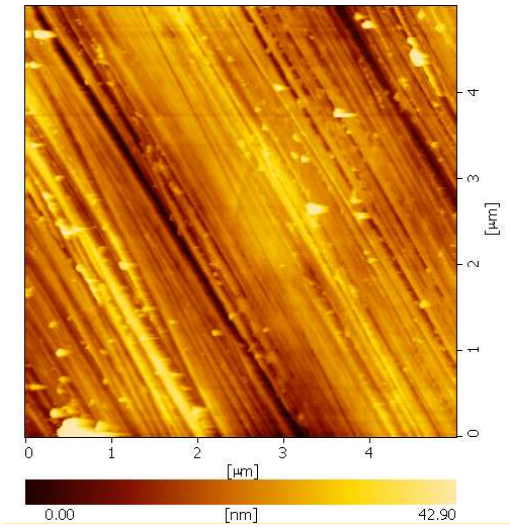

Fig. 1 AFM-topography image of specimen prepared by 1-µm diamond grinding (Characterization parameters: Seiko SPA 400 with 10-µm stage size, 0.5-Hz scan speed, and 5 µm x 5 µm scan area)

The microstructure of the plasma-nitride layer of hardened AISI D2 steel observed in this study was comparable to other plasma-nitride treated steel. Figure 2(a) shows nitride layer (~155-µm thick) consisting of diffusion layer and transition layer [4] and the inner unaffected area. In Figure 2(b), the diffusion layer in 1-µm diamond finishing was ~70-µm thick and can be clearly seen in electron micrograph because the image contrast was developed with respect to contributions from elemental information.

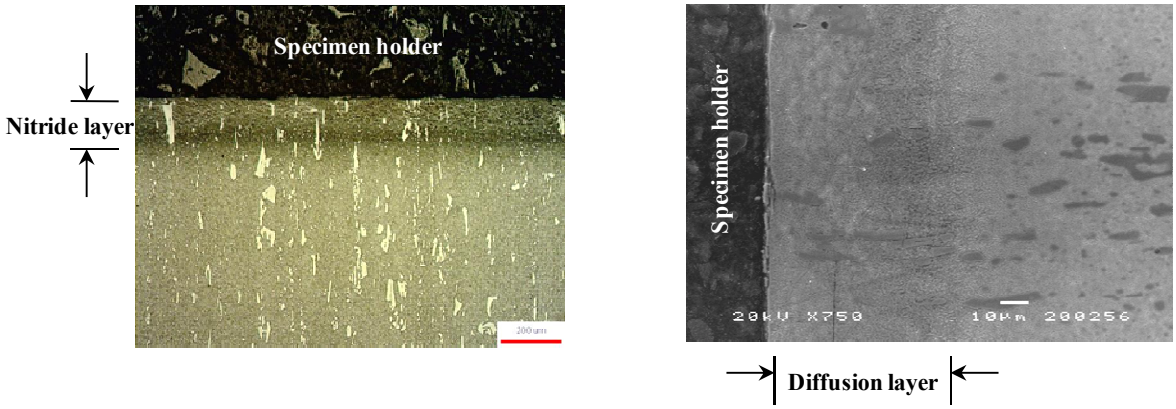

Fig. 2 (a) Optical micrograph, and (b) electron micrograph of plasma-nitride layer of hardened AISI D2 prepared using 1-µm diamond surface finishing

The thickness of the nitride layer appeared to increase the more finely the finish became. The nitride layer thickness measurement of the five non-directional surface finishing is summarized in Table 2. The present study result may be explained by the Snoek effect [5,6]. According to the experimental procedure, a series of surface grinding was introduced to the specimen surface while utilizing a compressive load perpendicular to the ground surface. This process used two motors to rotate the grinding media against the specimen. The mass of the specimen's rubbing surface was gradually removed as a result of the net shear force. The finer surface finishing required more steps to achieve the desired surface finishing while possibly introducing greater residual stress on specimen surface. Residual stress may contribute to the displacement of atoms along and underneath specimen surface. This allows the interstitial diffusion of nitrogen atoms during plasma nitriding leading to the formation of a thicker nitride layer for the specimen with finer surface finishing. Therefore, the results are consistent with the research in [1,2]. However, this effect also contributed significantly to the improvement in the nitride thickness when finishing with P800 grinding conditions versus that of P100 and P240. A relatively small difference in crystallographic deformation was produced when finishing with P800 grinding or other finer conditions.

Table 2 Average thickness of plasma-nitride layer prepared by five finishing conditions (Listed thickness values were averaged from 90 measurements/3 specimens.)

Finishing condition	Average thickness (µm)
P100	126.6±0.9
P240	132.1±0.9
P800	148±2
P2500	148±1
1-µm diamond	150±2

Vicker hardness measurement was performed along the cross-sectional area to evaluate the properties of the nitride layer at various positions from the surface. However, the hardness value at surface was characterized by indentation along the perpendicular direction to the top surface of nitride layer. Figure 3(a)-(e) compares the hardness profile for the plasma-nitride layer of the AISI D2 specimen prepared with various surface conditions and AISI D2 specimen without nitriding. The hardness value decreased the greater the distance from the specimen surface the measurement was taken. Critical depth, the range at which the greater hardness was measured in comparison with the non-nitride specimen, is estimated as 55 µm for finishing with roughness higher or equal to 0.023 µm (P100, P400, and P800 SiC grinding), and up to 80 µm for conditions with roughness value smaller or equal to 0.008 µm (P2500 and 1-µm diamond grinding). Figure 3(f) summarizes the mean of the

hardness profile. This suggests that finer surface conditions contribute to higher hardness values at the surface due to the greater amount of nitrogen diffusion which appears to be a result of crystallographic distortion. No significant difference in surface hardness in specimen prepared with 0.023-µm roughness value or more (P100, P400, and P800 grinding) were found 0 to 30 µm underneath its surface. However, greater hardness value through the nitride layer was observed at depths greater than 30 µm for specimen finished with P800 grinding. Moreover, preparing surface finishing with a roughness value of 0.008-µm less (P2500 and 1-µm diamond grinding) provided a greater mean hardness value than that of P800 grinding at every position underneath the surface. A comparison of the hardness and thickness results suggests that the finishing condition at any steps between P800 and P2500 grinding increases the hardness value at greater depth due to finer surface finishing which seems to increase nitrogen diffusion.

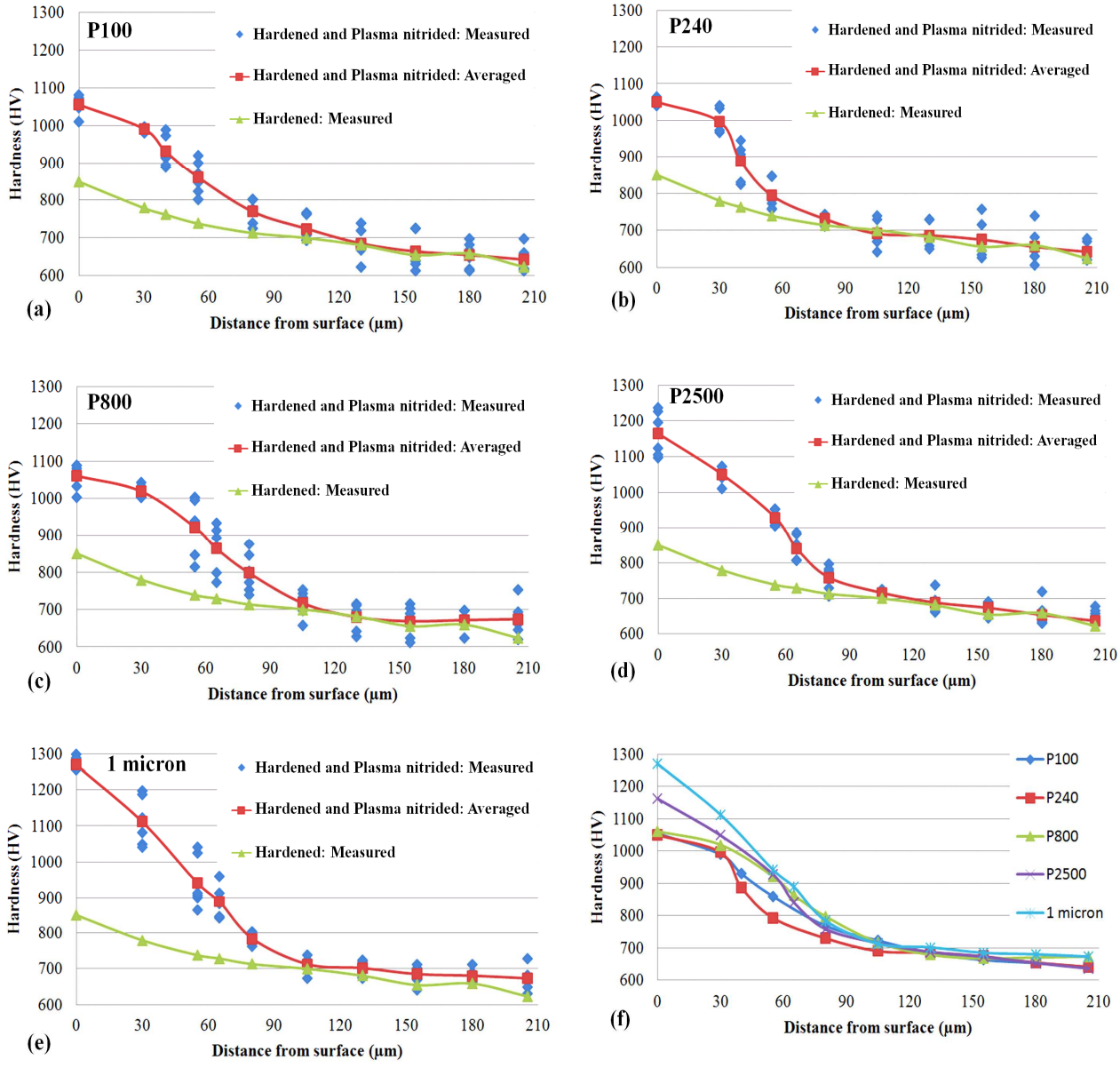

Fig. 3 Hardness profile for plasma-nitrided AISI D2 specimens prepared by (a) P100, (b) P240, (c) P800, (d) P2500, and (e) 1-µm diamond grinding (Hardness profile of specimen prior to nitriding is provided.) (f) summary of mean hardness profile from all finishing conditions

Summary

Outcome of this work can be used to advise the selection of surface finish conditions prior to plasma nitriding for hardened AISI D2 steel (Figure 4). In this experiment, surface finishing with a roughness value of at least 0.023-μm (P800 grinding) allowed a plasma-nitride layer with moderately good hardness profile and thick nitride layer compared to steel with finer finishing. In addition, coarser finishing takes less time and manpower thus costing less and more economical to produce. On the contrary, finer surface finishing, while more time consuming and laborious, can significantly increase the hardness profile and hardened depth from surface.

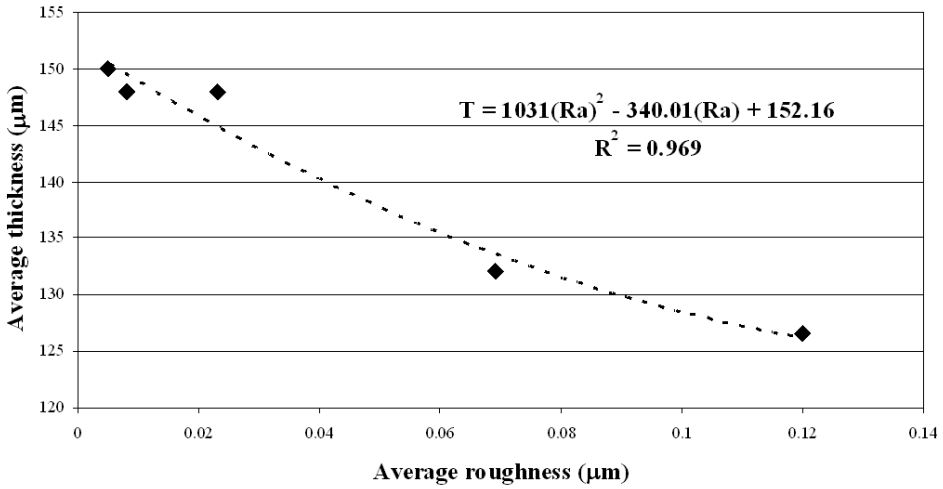

Fig. 4 Relationship between surface roughness prepared prior to plasma nitriding and thickness of plasma-nitride layer with regression analysis using 2nd-order polynomial function (T = average thickness, Ra = average roughness, and R^2 = coefficient of determination)

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References

[1]. S.S. Akhtar, A.F.M. Arif, B.S. Yilbas, A.K. Sheikh, Influence of surface preparation on the kinetics of controlled gas-nitrided AISI H13 steels used in extrusion dies. J. Mater. Eng. Perform. 19 (2010) 347-355.

[2]. A.daS. Rocha, T. Strohaecker, T. Hirsch, Effect of different surface states before plasma nitriding on properties and machining behavior of M2 high-speed steel. Surf. Coat. Technol. 165 (2003) 176-185.

[3]. G. Wroblewski, K. Skalaki, Properties of surface layer generated by new combined process of burnishing and nitriding, Surf. Eng. 22 (2006) 138-146.

[4]. D. Pye, Practical Nitriding and Ferritic Nitrocarburizing, ASM International, Ohio, 2003.

[5]. J. Snoek, Physica 6 (1939) 591.

[6]. R.E. Reed-Hill, Physical Metallurgy Principle, second ed., PWS-Kent Publishing Co, Boston, 1992.