THE INFLUENCE OF MACHINING WITH BLUNT MILL ON PLASMA NITRIDING OF X12Cr13 MARTENSITIC STAINLESS STEEL

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Abstract

Plasma nitriding is a thermochemical treatment, widely used in many technical applications as a final operation to improve the mechanical, tribological and corrosion properties of steel. This paper is focused on plasma nitriding treatment of X12Cr13 martensitic stainless steel. For nitriding of martensitic stainless steel was two stage plasma nitriding proces performed. The nitrided X12Cr13 stainless steel was characterized by measuring depth profiles and residual stress. Measuring of residual stress was carried out by X-ray diffraction on the Stresstech Xstress 3000 G2R device. To identify critical areas in terms of surface integrity was used Barhausen noise analysis. The verification of material chemical composition was carried out by OES Oxford FOUNDRY-MASTER device. The objective was to verify the nature of the residual stress before and after thermochemical treatment. The depths of the plasma nitride layers were estimated using cross-sectional microhardness profiles measuring. Microhardness and surface hardness of plasma nitrided steel samples were significantly increased. The samples prior and post thermochemical treatment showed significant differences of residual stress, which may be caused by machining with blunt tool, what has a significant influence on the creation of plasma nitride layer as well.

Keywords: Martensitic stainless steel, strain hardening, residual stresses, plasma nitriding

1. INTRODUCTION

The paper describes issues stainless steels machining in terms of chemical composition, physical and mechanical properties. This paper also deals with specification of stainless steels and corrosion resistant materials and cutting conditions. The issue of the machinability of stainless steels is in terms of their specific features interesting area.

Martensitic stainless steels are designed for high hardness. Their useful operating temperature range is restricted by their loss of ductility at sub-zero temperatures and loss of strength by over-tempering at high temperatures. Compared to common austenitic steels, these steels are characterized by lower corrosion resistance. These stainless steels are resistant to fresh water, dry atmospheres, and mild alkalies and acids, but comparatively lower resistante than the equivalent non-free-machining grades. High Sulphur content in free machining grades is not suitable for marine or other chlorides containing environments. The hardened steel with a smooth surface is needed to achieve the maximum of corrosion resistance [1,2].

Increasing of strength and hardness of the material below the machined surface is known under the concept of strain hardening. The degree of strain hardening of metal layer is assessed by microhardness measuring. The greatest microhardness exhibits chips, braked application layer and deformed layer. On the machined surfaces has the highest hardness the subsurface layer. The process of forming chips during metalworking is composed of complex heterogeneous deformation and destructive processes. The current approaches to definition of the mechanism of chips formation during cutting are largely based on geometric models [3,4].

2. EXPERIMENTAL PART

For experiment were designed two wheels with blades (see **Figure 1**). The half of individual blades was milled using blunt shank mill and half with was milled using shape shank mill under same cutting conditions. The diameter of the wheel was 230 mm with 18 blades. The material of wheel is martensitic stainless steel X12Cr13. The X12Cr13 stainless steel is in used for steam valves, pump shafts, bolts and miscellaneous parts production requiring corrosion resistance and moderate strength up to 500 °C.

Figure 1 Experimental X12Cr13 stainless steel wheel with blades

On the one of wheels was applied plasma nitiriding technology, this sample is denoted in the present paper as (PN sample), and second wheel was without plasma nitriding technology, this sample is denoted in the present paper as (NPN sample).

The parameters of the plasma nitriding process were designed according to used component and selected martensitic stainless steel. The plasma nitriding process was performed using two stage nitriding procedures. After plasma cleaning procedure at 515 °C for 45 min the first stage nitriding procedure was performed at 520 °C for 16 hours and followed by second stage of nitriding procedure, which was performed at 525 °C for 4 hours. Plasma nitriding process was performed in RÜBIG PN 70/120 device. After plasma nitriding process the experimental wheels were cut into individual stator blades [5,6].

Determination of the chemical composition was performed on the Oxford FOUNDRY-MASTER optical emission spectrometer. The results represent the composition of the core in the cross-sectional and are shown in the **Table 1** [7].

Table 1 Chemical composition of samples

C	Si	Mn	Cr	Ni	Mo	P	S
(1.4006): EN 10088-2-2005							
0.08 - 0.15	*max 1*	*max 1.5*	*11.5 - 13.5*	*max 0.75*	*0.15 - 0.25*	*max 0.035*	*max 0.035*
Chemical composition of NPN sample							
0.14	*0.51*	*0.37*	*12.7*	*0.07*	*0.594*	*0.011*	*0.003*
Chemical composition of PN sample							
0.02	*0.49*	*0.43*	*12.9*	*0.09*	*0.534*	*0.016*	*0.014*

For the PN sample, the lower carbon content is probably the result of technological decarburization. Deeper grinding before the diffractometric measurement was a threat to thermal influence.

Residual stress measurements were performed on a Stresstech Xstress 3000 G2R diffractometer. The measurement sites were determined using a previous Barhausen noise analysis. The residual stress was determined in two directions (**Figure 2**) [8,9].

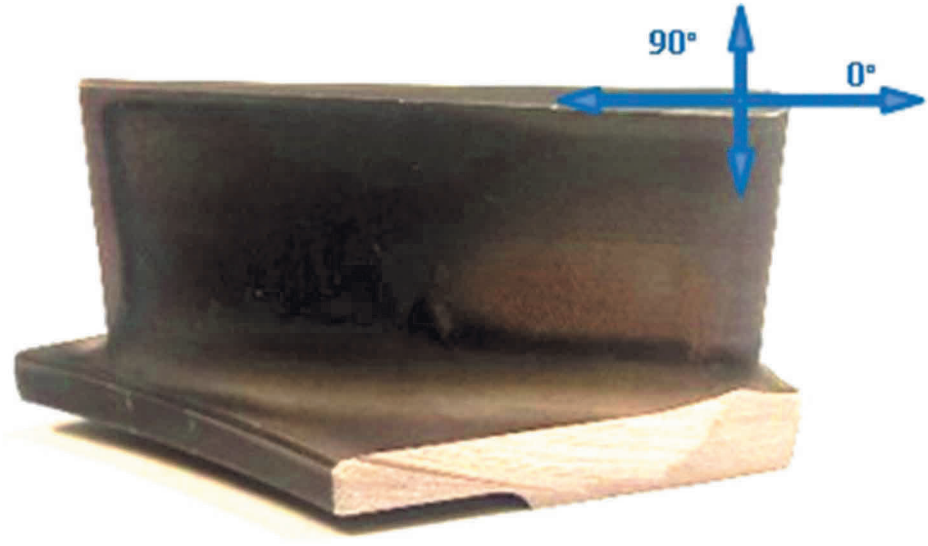

Figure 2 The directions of residual stress measuring

Direction 0° is indicated in the following residual stress graphs and shown in a red line, and the 90° direction is shown in blue. In this way, measurements were taken on all samples. The results of measurements are shown in individual graphs of dependence of residual stress at depth below the surface. The results of measurements are showed in **Figure 3** and in **Figure 5** [10].

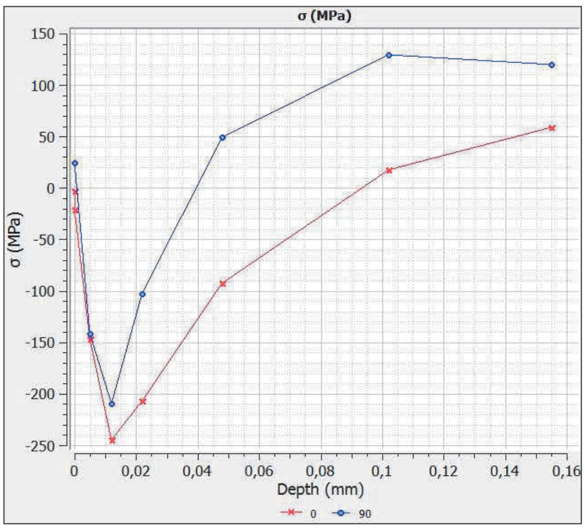

Figure 3 Residual stress of NPN sample

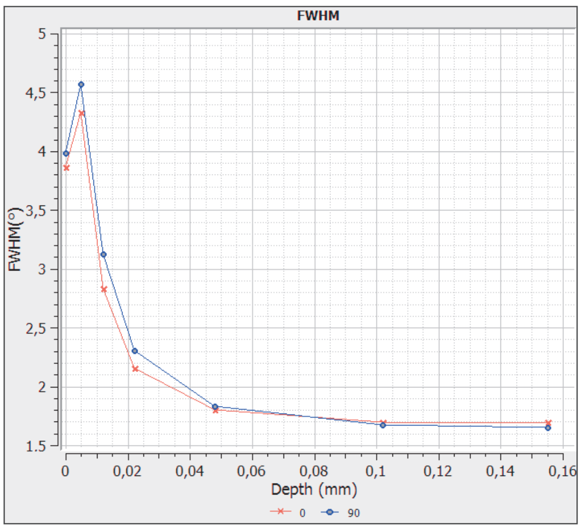

Figure 4 FWHM of NPN sample

Another measured magnitude is the width of diffraction peak at half maximum (Full Width at Half Maximum-FWHM). This parameter is dependent on the structure of the monitored material, reflecting information on material hardness and micro-stress. FWHM values are shown in the secondary graphs as a dependency of FWHM on the depth, see **Figure 4** and **Figure 6** [10,11].

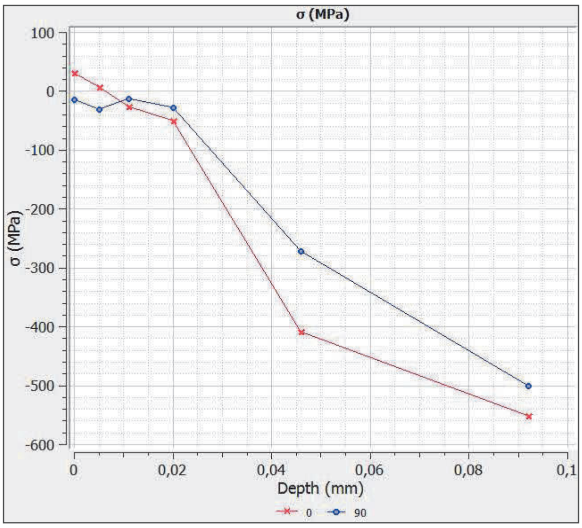

Figure 5 Residual stress of PN sample

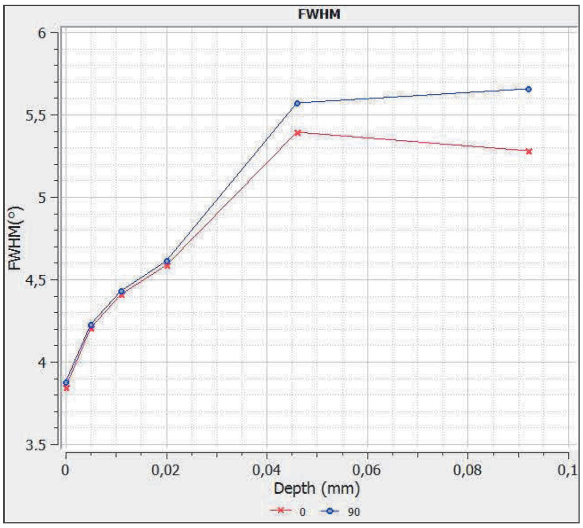

Figure 6 FWHM of PN sample

The microhardness of strain hardening layer and plasma nitrided layer thickness was evaluated using automatic microhardness tester LM 247 AT LECO equipped by AMH43 software [12]. The test load for microhardness of strain hardening layer was set at 5 g and 10 s dwell time. The test load for plasma nitride layer was set at 50 g and 10 s dwell time. The micro-hardness of the samples of martensitic stainless steel X12Cr13 are plotted in **Figure 7** and **Figure 8** [13,14].

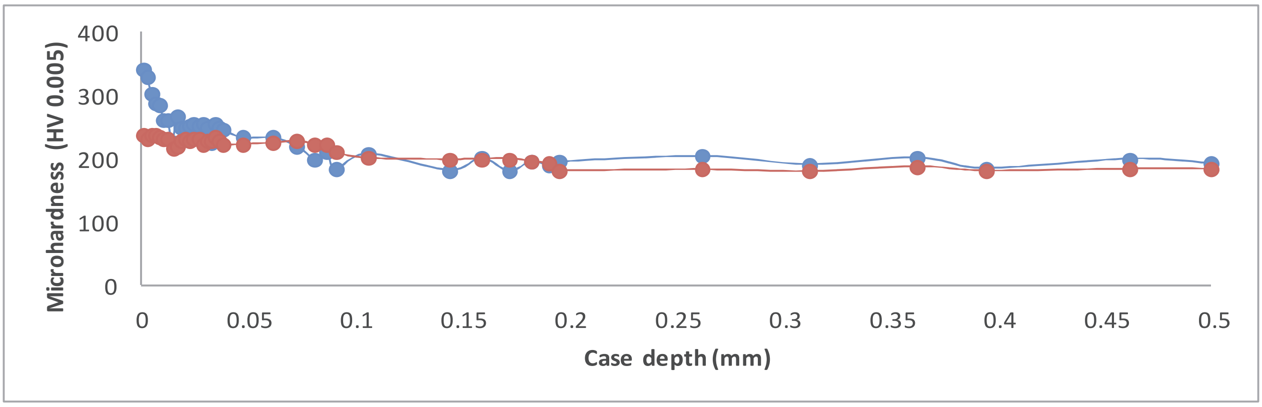

Figure 7 Microhardness depth profile of NPN sample

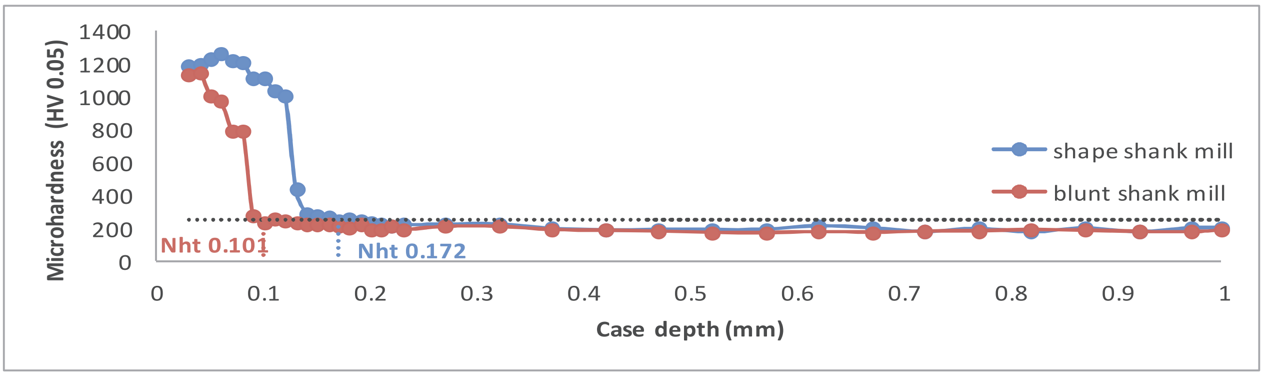

Figure 8 Microhardness depth profile of PN sample

The microstructures of the strain hardened layers and the plasma nitrided layers of all samples were cross-sectionally documented by optical microscopy Olympus GX51. The microstructure of the foot of the NPN blade after machining by blunt mill is displayed in **Figure 9** [15].

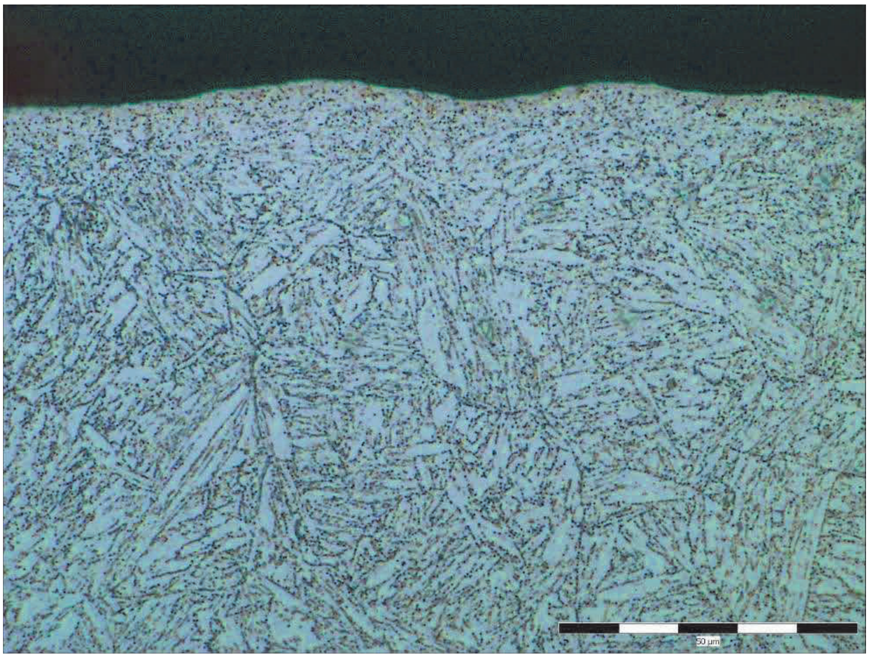

Figure 9 The microstructure of the NPN sample after machining by blunt mill, mag. 1000x

3. RESULTS

Experimentally was confirmed that the machining with blunt mill has influence on the diffusivity and layer creation of plasma nitriding process. The microhardness of NPN sample increased from 237 HV0.005 to 340 HV0.005 after machining with blunt tool, see **Figure 7**. Measurements of microhardness have shown that the strain hardened layer had a significant influence on the nitrided layer creation. The nitrided layer thickness was different by using blunt or shape tool. The nitrided layer thickness of 101 µm was created after milling with blunt mill. After milling with shape mill the thickness of nitride layer was increased to 172 µm, see **Figure 8**. From residual stress patterns at the depth below the surface is seen that the compressive stresses in the near-subsurface layers are significant pressures (200 - 500 MPa). Stresses achieve equilibrium at depth of 50 µm (± 100 MPa).

4. CONCLUSION

The experiment showed that the machining with a blunt tool causes to create the strain hardening layer, especially at the foot of the blade. After plasma nitriding, the mechanical properties of steels were improved. The experimental results showed that plasma nitriding of martensitic X12Cr13 stainless steel increases the microhardness and surface hardness. Comparing the NPN sample and the PN sample showed significant differences in the measured residual stress directions that may be caused by machining influences. From FWHM dependence on depth, it is evident that the hardness of the surface layer at a depth of about 50 µm decreases rapidly and corresponds to the values of the heat-untreated material. The samples prior and post thermochemical treatment showed significant differences of residual stress which may be caused by machining with blunt tool, what has a significant influence on the creation of plasma nitrided layer as well. The experimental results showed that the machining with blunt shank mill has an adverse influence on the diffusion and nitrided layers creation during the plasma nitriding process (**Figure 8**).

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