

INFLUENCE OF THE CARBONITRIDING TO CHANGE THE SURFACE TOPOGRAPHY OF 16MnCr5 STEEL

DOBROCKÝ David¹, POKORNÝ Zdeněk¹, STUDENÝ Zbyněk¹, ŠURLÁKOVÁ Mária²

¹University of Defence, Faculty of Military Technology, Brno, Czech Republic, EU

²Alexander Dubček University of Trenčín, Faculty of Special Technology, Trenčín, Slovakia, EU

Abstract

Carbonitriding combines the effects of saturation of the surface of the component with nitrogen and carbon simultaneously. The layer has a hardness approaching 1000 HV and is highly resistant to galling and abrasion. For this reason, carbonitriding components are used in applications with high demands on thermal load and wear resistance (e.g. valves of internal combustion engines, segments of crankshafts, etc.). Mostly in case of components after carbonitriding are not required subsequent grinding due to a minimum increase of the dimensions and small changes in surface roughness. Presented work documents a change of parameters of the surface topography of 16MnCr5 steel after carbonitriding in gas and plasma. The layers were applied to the grinded surfaces of the specimens and then compared. The surface morphology and 2D and 3D surface parameters were measured. After carbonitriding considerable porosity of the resulting layer was found, especially after carbonitriding in gas. Applications of carbonitriding both in gas and plasma resulted in only a slight increase observed roughness parameters.

Keywords: Carbonitriding, surface topography, surface roughness

1. INTRODUCTION

During the carbonitriding process, the steel surface is simultaneously saturated with nitrogen and carbon for a period of usually 2 to 4 hours at 600 °C ± 20 °C [1]. The process is most commonly used for carbonitriding of drives and valve gears, gears, steering levers, cams and crankshafts, connecting rods, clutch plates, cylinder inserts, etc. [2]. During the process, a layer of carbonitrides with a thickness of 10 µm (2 hours of process) to 50 µm (4 hours of process) is created on the surface which contains about 8% nitrogen, 2% carbon and 1% oxygen [3]. Hardness of the layer is 950 - 1000 HV. The layer is very resistant to abrasion and grinding, the corrosion resistance is increased [4]. On the surface of the layer there are visible very fine pores at a small magnification (25x), the porosity of the layer is documented even at high magnifications (5.000x) [5]. Under this layer of nitrides, about 1 mm layer of ferrite with nitrogen is situated [6]. By cooling from the temperature of the carbonitriding to the oil a supersaturated solution is formed in this layer, which is spontaneously cured by excluding the fine particles of FeN to 300 - 400 HV. This diffusion layer supports load bearing capacity of carbonitrides layer and increases fatigue limit up to 100%. The deformation of the carbonitrided components is very small in the process, dimensions increase by about 0.01 mm. Carbonitriding is carried out in a gaseous atmosphere or using plasma in furnaces.

An important evaluation parameter of layer is also the texture of its surface, which influences in particular the wear parameters and therefore the life of the components. The surfaces of the components must be suitably prepared before the carbonitriding process. Standardly prepared surfaces of real components, such as gearwheels, after grinding are expressed by the Ra parameter in the range of 0.05 to 0.4 µm, depending on the technology of cutting operation. In the paper, 2D and 3D surface texture parameters were evaluated on 16MnCr5 steel samples. Samples were prepared using MTH Micron 150 metallographic saw and Struers Labopol 60 grinder, then were carbonitrided in gas and plasma. Measurement of 2D and 3D parameters was

performed using the absolute method on the Talysurf CLI 1000 device and evaluated by the Talymap Platinum measuring software. Surface morphology was documented using the Hitachi TableTop 3300 electron microscope. The chemical composition of the evaluated steel was analyzed by the Q4 Tasman emission spectrometer.

2. EXPERIMENTAL METHODS

2.1. Chemical composition of analyzed steel

The chemical composition of the analyzed steel was performed using a Q4 Tasman spark optical emission spectrometer. The results of the chemical composition of the analyzed 16MnCr5 steel and their comparison with the standard are given in **Table 1**. After analyzing of the chemical composition, the samples in shape of discs of Ø 50 mm and thickness of 10 mm was cut using the MTH Micron 150 metallographic saw.

Table 1 Chemical composition of 16MnCr5 steel

C	Mn	Si	Cr	P	S	Ni	Mo	V	Al	Cu
Q4 Tasman										
0.156	1.083	0.280	1.042	0.011	0.008	0.053	0.011	0.002	0.002	0.131
DIN Standard										
0.14- 0.19	1.10- 1.40	0.17- 0.37	0.80- 1.10	max. 0.035	max. 0.035	-	-	-	-	-

2.2. Heat treatment and carbonitriding

The choice of heat treatment was chosen with respect to the strength characteristics of the components which are really used. The steel was quenched with the ensuing tempering on the middle limit of the strength. The samples were grinded with using water as a cooling medium on sanding papers of 80 - 600 µm grain size according to FEPA after heat treatment. Thus prepared samples were carbonitrided in plasma and in the gas with followed oxidation. The basic parameters of heat treatment and carbonitriding are given in **Table 2**.

Table 2 Parameters of heat treatment and carbonitriding

Quenching	Tempering	Carbonitriding	
		Plasma	Gas
850 °C/water	600 °C/water	530 °C/4 h	540 °C/6 h

2.3. Measurement of surface texture and evaluation of surface morphology

Measurement of the surface texture was performed in the case of 2D and 3D parameters using the absolute method on the Talysurf CLI 1000 profilometer. To obtain the representative results of measured roughness parameters, the cut-off values were determined in accordance with CSN EN ISO 4288. The basic length of the measured profile in the case of 2D parameters was $\Lambda_c = 0.8$ mm, evaluated length $L = 4$ mm, cut-off = 0.08 mm. 3D parameters were evaluated on an area of 2.5 x 2.5 mm, at cut-off = 0.25 mm. Measurement of 2D and 3D surface texture parameters was evaluated by the Talymap Platinum software. The texture characteristics of the sample surfaces before and after carbonitriding are given in Chapter 3 Results and discussion. The SE method on the Hitachi Table Top 3300 electron microscope was used to document surface morphology. Surface morphology was observed at magnification of 5.000x.

3. RESULTS AND DISCUSSION

2D parameters were evaluated on each sample from 6 measurements and were calculated as the average value of all evaluated lengths. The following parameters were selected to compare 2D surface texture of samples:

- Ra: Arithmetic Mean Deviation of the roughness profile,
- Rq: Root-Mean-Square (RMS) Deviation of the roughness profile,
- Rz: Maximum Height of roughness profile,
- Rt: Total Height of roughness profile,
- RSm: Mean Width of the roughness profile elements.

Comparison of 2D parameters of grinded samples and carbonitrided samples in plasma and gas is shown in **Table 3**. From the measured results of the 2D parameters it is clear that the surface roughness parameters reach the lowest values in the case of carbonitriding in the plasma, even when compared with the grinded surfaces of the experimental samples. After carbonitriding in the gas, the 2D roughness parameters deteriorated by one order, compared to plasma carbonitriding and grinded surfaces.

Table 3 Roughness parameters (2D) of experimental samples

Parameter	Grinded surface	Carbonitrided surface	
		Plasma	Gas
Ra	0.0968 ± 0.0017 μm	0.0673 ± 0.00395 μm	0.131 ± 0.0127 μm
Rq	0.136 ± 0.00196 μm	0.113 ± 0.0059 μm	0.186 ± 0.0213 μm
Rz	1.38 ± 0.0235 μm	1.42 ± 0.0199 μm	2.28 ± 0.0797 μm
Rt	1.51 ± 0.0167 μm	1.51 ± 0.0336 μm	3.02 ± 0.466 μm
RSm	0.0154 ± 0.000602 mm	0.0152 ± 0.000784 mm	0.024 ± 0.00889 mm

In case of 3D parameters, roughness parameters and waviness parameters were evaluated. The amplitude parameters (Sa, Sq, Sz, St) and functional parameters (Sk, Spk, Svk, Sr1, Sr2) were chosen for comparison of the evaluated surfaces:

- Sa: Arithmetic Mean Deviation of the Surface,
- Sq: Root-Mean-Square (RMS) Deviation of the Surface,
- Sz: Ten Point Height of the Surface,
- St: Total Height of the Surface,
- Sk: Core Roughness Depth,
- Spk: Reduced Summit Height,
- Svk: Reduced Valley Depth,
- Sr1: Upper Bearing Area,
- Sr2: Lower Bearing Area.

Comparison of the evaluated 3D parameters of the grinded samples and samples carbonitrided in plasma and gas is documented in **Table 4**. The measured results show that the 3D parameters of roughness and waviness have the lowest values in the case of grinded surfaces (but not for all parameters). Lower values of 3D parameters of roughness were achieved in plasma carbonitrided samples, while carbonitriding in the gas reached lower values of 3D parameters of waviness.

Table 4 3D parameters of experimental samples

Parameter	Grinded surface		Carbonitrided surface			
			Plasma		Gas	
	Roughness	Waviness	Roughness	Waviness	Roughness	Waviness
Sa	0.0164 μm	0.0603 μm	0.183 μm	0.103 μm	0.21 μm	0.0761 μm
Sq	0.21 μm	0.0743 μm	0.233 μm	0.142 μm	0.267 μm	0.0994 μm
Sz	2.85 μm	0.436 μm	2.74 μm	0.86 μm	2.96 μm	0.633 μm
St	3.54 μm	0.492 μm	3.47 μm	0.924 μm	4.64 μm	0.794 μm
Sk	0.331 μm	0.0831 μm	0.388 μm	0.102 μm	0.483 μm	0.0721 μm
Spk	0.142 μm	0.0241 μm	0.111 μm	0.036 μm	0.133 μm	0.03 μm
Svk	0.126 μm	0.0244 μm	0.212 μm	0.0491 μm	0.162 μm	0.0312 μm
Sr1	10.7 %	9.73 %	4.4 %	7.97 %	8.42 %	9.14 %
Sr2	87.8 %	91.2 %	88.4 %	88.8 %	91.3 %	89.7 %

The 3D graphic representation of the analyzed surfaces (Roughness, Waviness) is for grinded surfaces shown in **Figure 1**. In **Figure 2**, they are surfaces carbonitrided in plasma, and **Figure 3** documents surfaces after carbonitriding in gas.

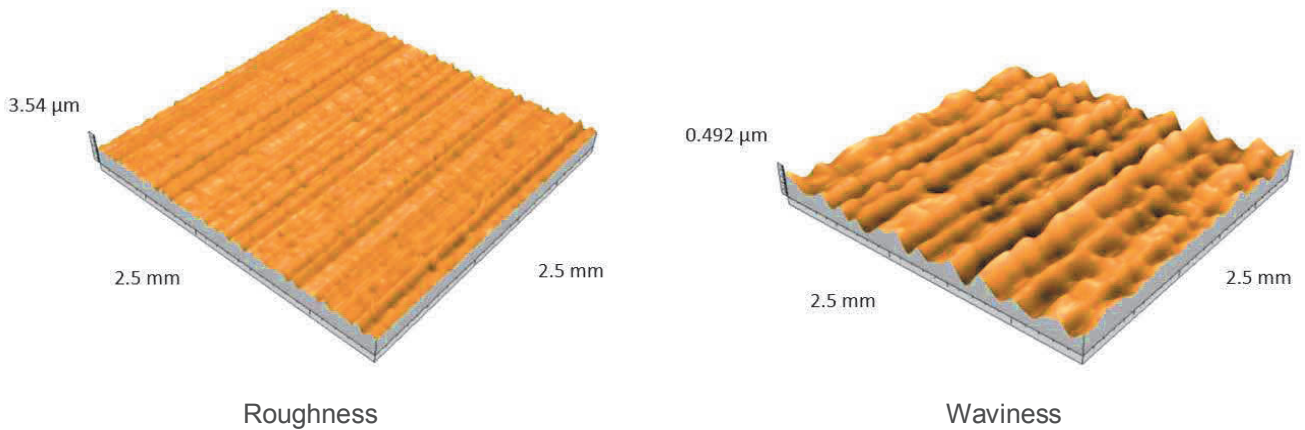


Figure 1 Analyzed area of grinded surface

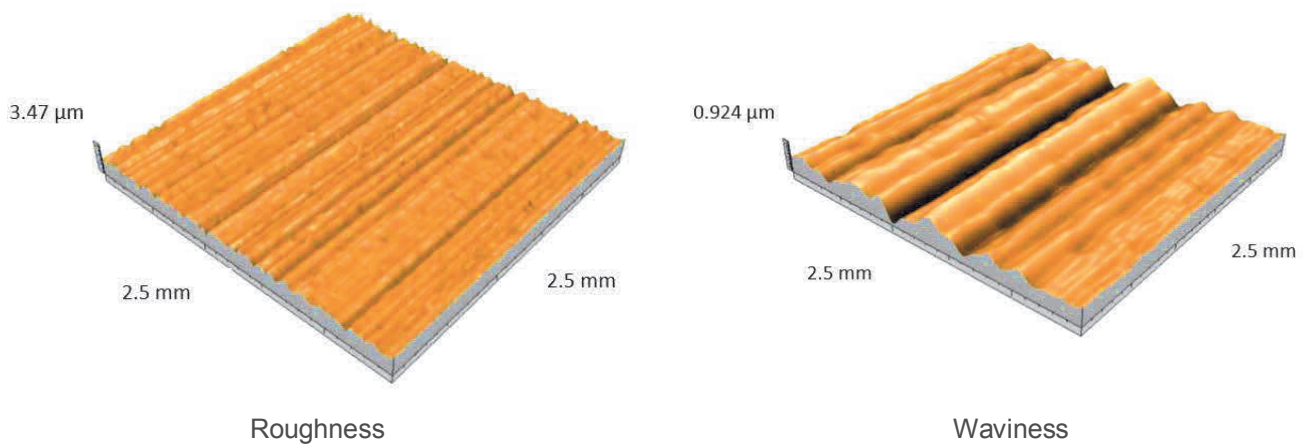


Figure 2 Analyzed area of carbonitrided surface - carbonitriding in plasma

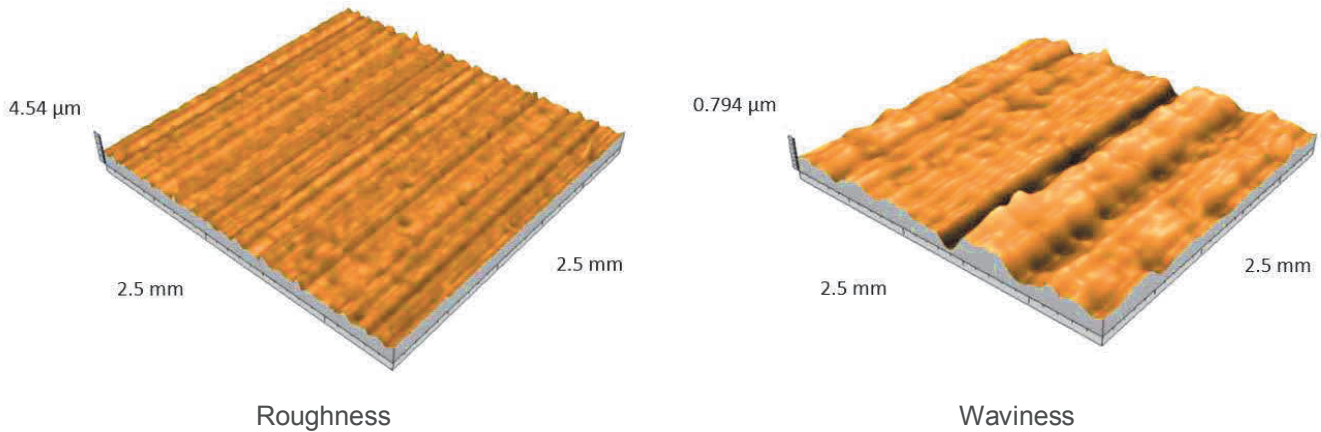


Figure 3 Analyzed area of carbonitrided surface - carbonitriding in gas

The morphology of the surface after carbonitriding application differs from the grinded surface and has a significant impact on the life of the components. For this reason, surfaces formed after carbonitriding in plasma and gas, were observed. It was expected that, especially after carbonitriding in the gas, a considerable porosity of the layer would be observed because the information on the existence of porosity in the diffusion layers is widely published in the literature [7, 8]. The morphology of the surfaces of carbonitrided samples in plasma and gas and the cross-section of the compound layer are shown in **Figure 4** and **Figure 5**.

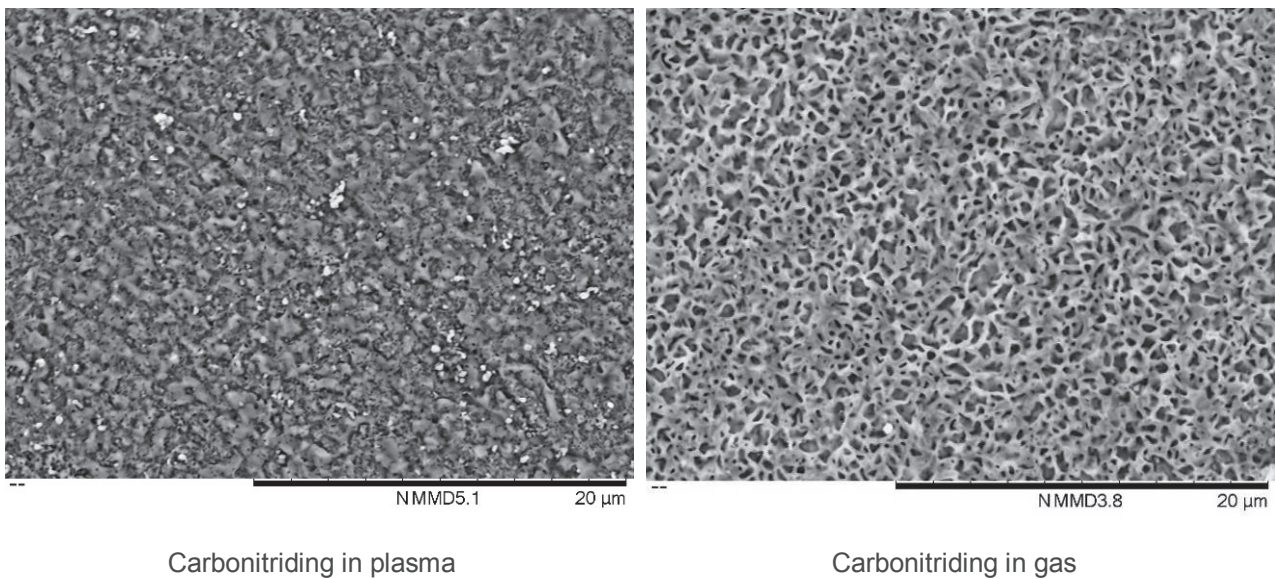


Figure 4 Morfology of surface after carbonitriding in plasma and in gas (magnification 5.000x)

The morphology of surfaces after carbonitriding in plasma and gas differs mainly due to the working environment used. After carbonitriding in the plasma, surface with a low occurrence of pores which have a small size was achieved. After carbonitriding in the gas, a large number of pores have been shown. The pores in the compound layer form cavities, which is evident from the cross-section of the compound layer. The cavities may represent stress concentrators in the surface layer. After carbonitriding in the gas, on the surface of the steel there are shapes copying the original austenitic grains, which is again visible from the cross-section of the compound layer.

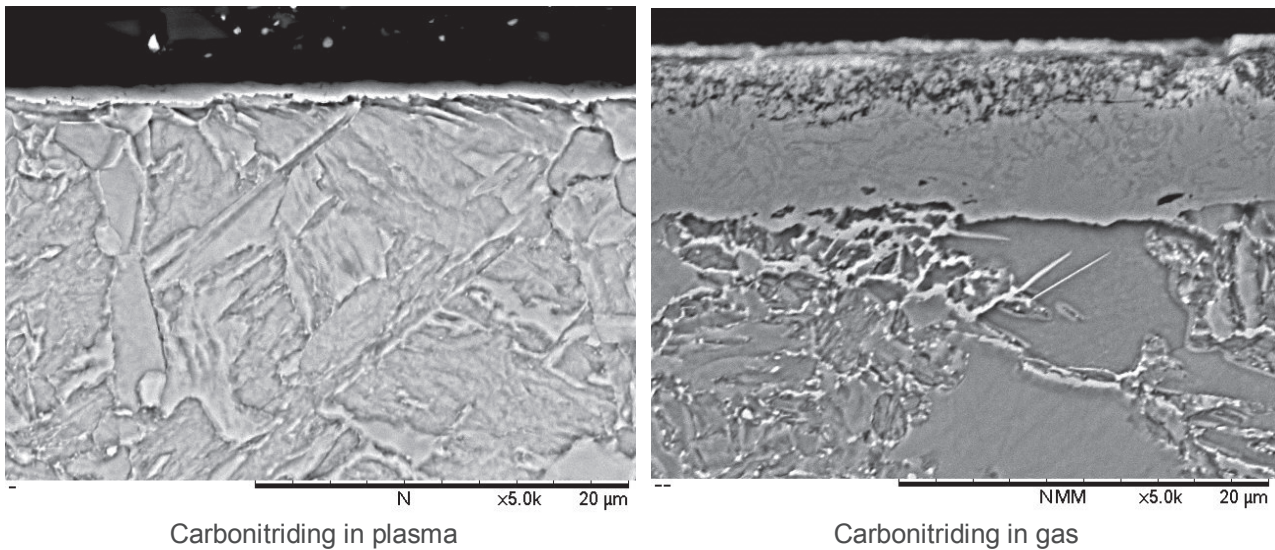


Figure 5 A pore-free compound layer in case of carbonitriding in plasma and porosity of compound layer in case of carbonitriding in gas (magnification 5.000x)

4. CONCLUSION

In order to modify the final surface of the components without any subsequent grinding, the optimal use of such diffusion technologies, which demonstrably do not show an enormous increase in roughness parameters and for which the pore incidence rate can be demonstrably eliminated. After carbonitriding in plasma, the surface texture parameters were slightly increased. Even in case of 2D parameters, better roughness values have been achieved compared with grinded surfaces. Carbonitriding in the gas exhibited the worst values of the observed 2D parameters, which varied in one order of comparison with the plasma carbonitriding. However, with both technologies, it can be said that the increasing of the surface texture parameters does not reach large values and is still in line with the requirements that are required for this type of surface treatment. Similar results were achieved even with the 3D parameters being evaluated. After carbonitriding in plasma and gas, the assessed 3D parameters of roughness and waviness have deteriorated compared with grinded surfaces. Carbonitriding in plasma has achieved better results in case of 3D parameters of roughness, while carbonitriding in the gas has better 3D parameters of waviness. Surface morphology clearly demonstrates higher occurrence of pores in the compound layer after carbonitriding in the gas. The pores observed in the compound layer form cavities that may be stress concentrators, and as a result of their occurrence, premature pitting may occur in areas of direct contact of the components. For this reason, after carbonitriding in the gas, it is advisable to ensure the surface layer is delaminated and ensure only a pore-free compound layer. After carbonitriding in plasma, the relief of surface is more compact than carbonitriding in the gas and less porous. In conclusion, with slight changes in surface texture parameters and low occurrence of pores in the compound layer, carbonitriding in plasma may be recommended from the point of view of surface morphology as the final surface finish of components without the need for grinding.

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