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Surface Topography of Nitrided Steel Surfaces

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Abstract. The effect of nitrocarburizing were investigated for two different steels, 42CrMo4 and 25CrMo4, with objective to evaluate the influence of initial surface topography on the resulting nitrocarburized surface with regard to surface topography and thickness of the compound layer. It was found that the nitrocarburizing process has an impact on the surface topography. The process creates a short-wave isotropic structure on the original surface and this is particularly evident for the smoother original surfaces. No significant effect on the compound layer thickness depending on the surface topography before heat treatment could be observed.

1. Introduction

Currently, case hardening is the most common heat treatment method for larger volumes of high strength steel components. Nitriding and nitrocarburizing are some of the more interesting alternatives [1], [2]. These processes allow in several ways reduced environmental loads, both at production and during the life time of the product in use. In many cases components with low friction and good wear resistance are desired, e.g hydraulic components, pistons, gear wheels and tools [3], [4].

Compared to case hardening additional production benefits are provided such as less distortion and reduced energy consumption [3]. During the service life of the product commonly obtained benefits are improved component performance due to good surface properties (friction and wear) [5], [6], improved fatigue strength [3], [7] and increased corrosion resistance [8], [9]. These properties are also known to be affected by the surface topography. Low friction powertrain-components are needed in order to meet requirements for lower fuel consumption in the automotive industry. For these kinds of applications nitriding processes, combined with a suitable steel, are of great interest [3].

The surface topography of the heat treated component will be influenced by the nitriding process [10]. It is additionally hypothesised that the result will depend on the topography of the original surface, before treatment. However, this effect is not well documented in the literature. In many studies the samples are prepared to have the same initial surface characteristics [10]–[12].

The objective of the present study was to evaluate the influence of initial surface topography on the resulting nitrocarburized surface with regard to surface topography and thickness of the compound layer after nitrocarburizing.

2. Materials and methods

Two different steel materials were used in the present investigation, 42CrMo4 and 25CrMo4. The steels were atmospheric nitrocarburized for 150 min in 580°C. With the 42CrMo4 steel 4 samples were created with different surface finish by polishing to different levels. The 25CrMo4 steel was used

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in a real hydraulic motor component from which 5 samples were taken with surfaces created by different machining processes, see Table 1. The compound layer has been analysed using Light Optical Microscopy (LOM).

Surface topography of the samples was measured and analysed before and after heat treatment. The 42CrMo4 samples were relocated so that the same area could be analysed before and after heat treatment. The relocation was performed by means of indentations on the surface that were visible. The indentations were used to shift and rotate the surface so that the same regions were measured before and after treatment. The 25CrMo4 samples were not relocated due to geometry dependent practical reasons. The topography measurements were made using an Olympus LEXT OLS3100 confocal instrument [13].Stitching (3x3) and analysis were made with the software MountainsMap from Digital Surf. Measurement size and resolution were chosen depending on the surface texture. Form removal with 2'nd order polynomial and noise reduction was applied to the measured surfaces before analysis to provide S-F surfaces. The data sets were also cropped to create pairs of the same size, before and after heat treatment. See Table 1 for details on the analysed data sets.

Selected surface roughness parameters were calculated according to ISO 25178-2 [14]. The parameters Sa, Sdr and Str were selected since they represent different characteristics of the surface that were thought to be relevant to study. Sa, arithmetical mean height of the surface, is a commonly used parameter for areal characterisation of surface roughness. In many ways it is a areal equivalent to the traditionally used profile Ra [15]. However, the use of Ra also implies the use of certain filtering, which is not the case for Sa [16]. Sdr, developed interfacial area ratio, is used as a measure of the surface complexity, especially in comparisons between several stages of processing on a surface. It can be helpful with discriminating between surfaces with similar Sa but with different textures within the shorter wavelengths since longer wavelengths on a surface tend to have higher amplitudes than shorter wavelengths and will often therefore dominate the Sa value [17], [18]. Str, texture aspect ratio, characterises the isotropy of the surface. The Str parameter is unit-less and its values is between 0 and 1. If Str is close to 1 the surface is isotropic, which means that it has the same properties regardless of the direction. If Str is close to 0 the surface is anisotropic, which means that it has a dominant texture direction [16].

Table 1. Samples materials, size of analysed area and lateral resolution for topography measurements.

Sample	Steel	Analysed area (μm)	Lateral resolution (μm)	Objective lens
80 grit paper	42CrMo4	1560 x 1560	0.625	20x
320 grit paper	42CrMo4	1250 x 1250	0.625	20x
800 grit paper	42CrMo4	600 x 600	0.250	50x
8000 grit paper	42CrMo4	625 x 625	0.250	50x
Ground	25CrMo4	650 x 650	0.250	50x
Rough turned	25CrMo4	1310 x1310	0.625	20x
Finish turned	25CrMo4	1370 x 1370	0.625	20x
Finish milled	25CrMo4	625 x 625	0.250	50x
Reamed	25CrMo4	1620 x 1620	0.625	50x

3. Results: Surface topography

3.1. Steel 42CrMo4 prepared with 80 grit paper

Before and after heat treatment, see **Figure 1**. Observations:

- Lower Sa, smoother surface
- Slight increase in Sdr, more presence of a shorter wavelength texture
- Str is similar, the bigger scratches dominates and are still apparent after heat treatment

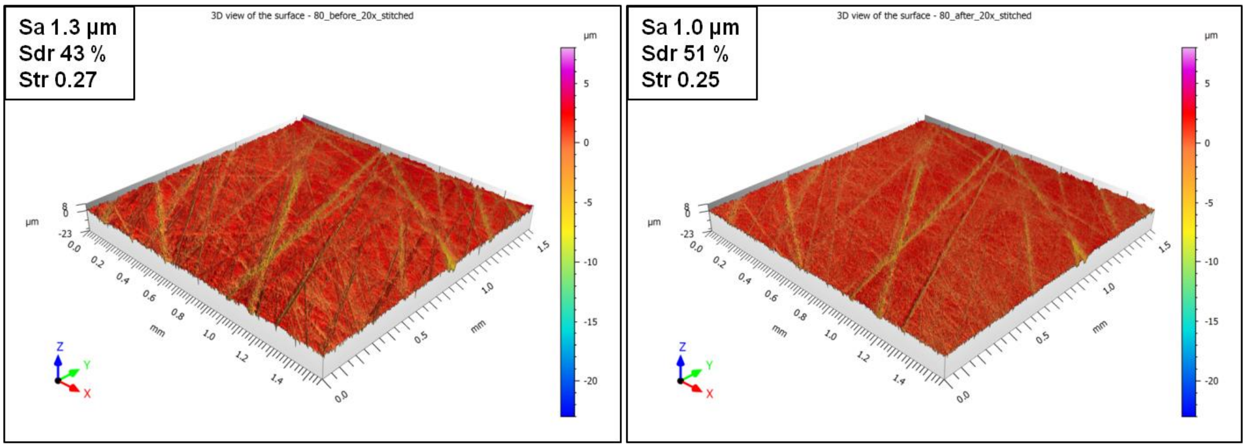

Figure 1. Topography of surface '80 grit paper' before (left) and after (right) nitrocarburizing, relocated. Steel 42CrMo4.

3.2. Steel 42CrMo4 prepared with 320 grit paper

Before and after heat treatment, see **Figure 2**. Observations:

- Sa is similar
- Increase in Sdr, more presence of a shorter wavelength texture
- Clear anisotropic texture with polishing scratches before, low Str. After nitrocarburizing the surface is different and isotropic, high Str

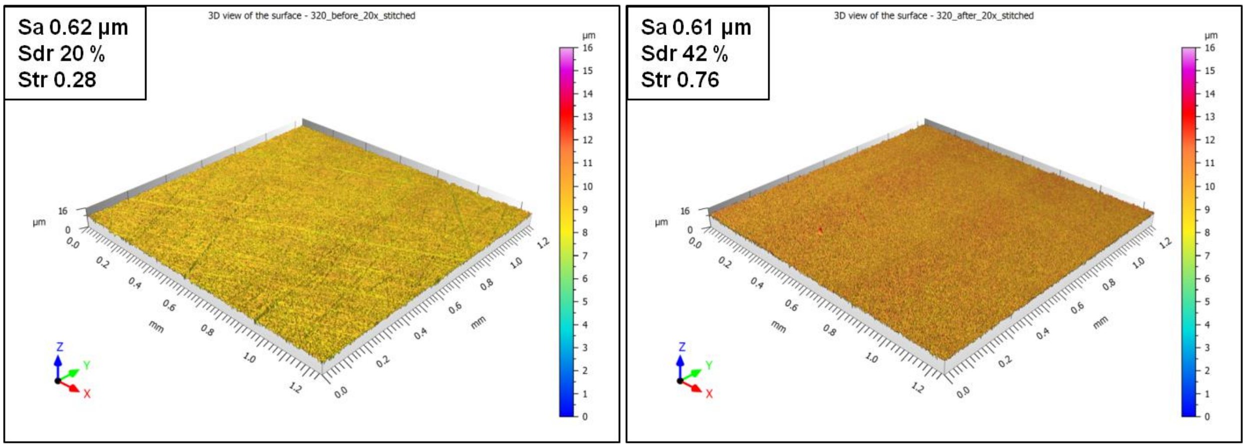

Figure 2. Topography of surface '320 grit paper' before (left) and after (right) nitrocarburizing, relocated. Steel 42CrMo4.

3.3. Steel 42CrMo4 prepared with 800 grit paper

Before and after heat treatment, see **Figure 3**. Observations:

- Before the surface is smooth with polishing scratches. Low Sa, Sdr and Str
- After, nothing of the previous texture can be seen, instead there is a much rougher isotropic texture. Higher Sa, Sdr and Str

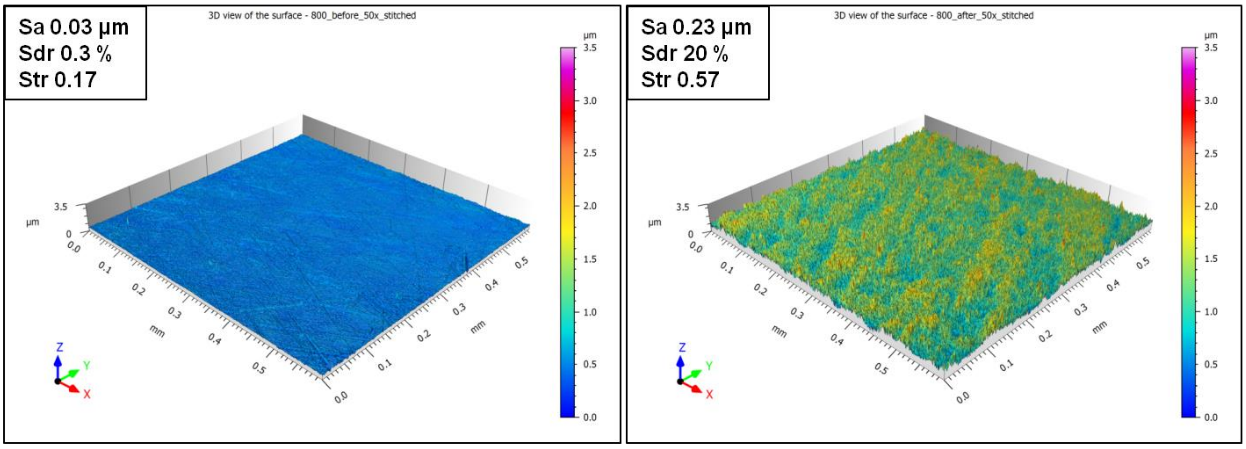

Figure 3. Topography of surface '800 grit paper' before (left) and after (right) nitrocarburizing, relocated. Steel 42CrMo4.

3.4. Steel 42CrMo4 prepared with 4000 grit paper

Before and after heat treatment, see **Figure 4**. Observations:

- Before the surface is smooth with some polishing scratches. Low Sa, Sdr and medium Str
- After, nothing of the previous texture can be seen, instead there is a much rougher and more isotropic texture. Higher Sa, Sdr and Str

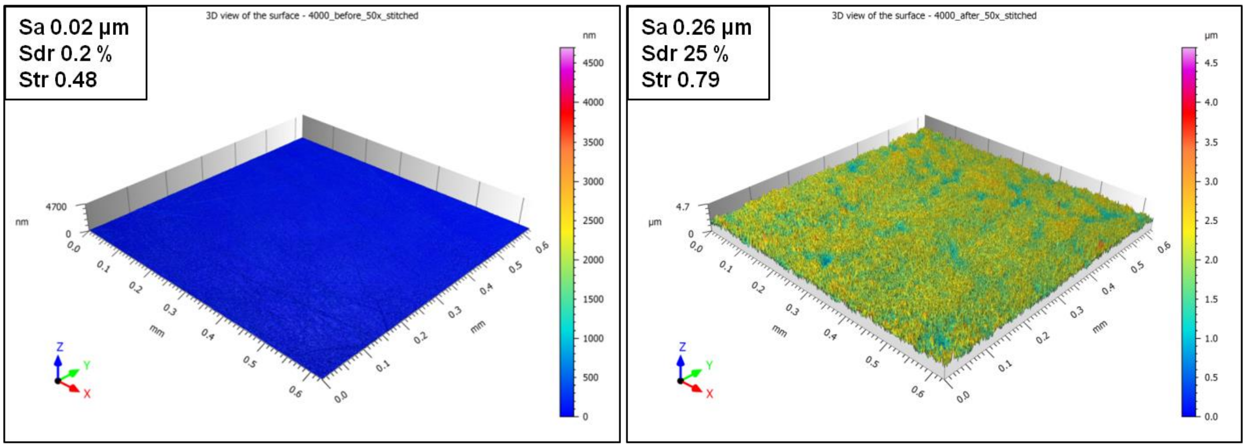

Figure 4. Topography of surface '4000 grit paper' before (left) and after (right) nitrocarburizing, relocated. Steel 42CrMo4.

3.5. Steel 25CrMo4 ground

Before and after heat treatment, see **Figure 5**. Observations:

- Similar Sa
- Slight increase in Sdr
- No big difference before and after heat treatment

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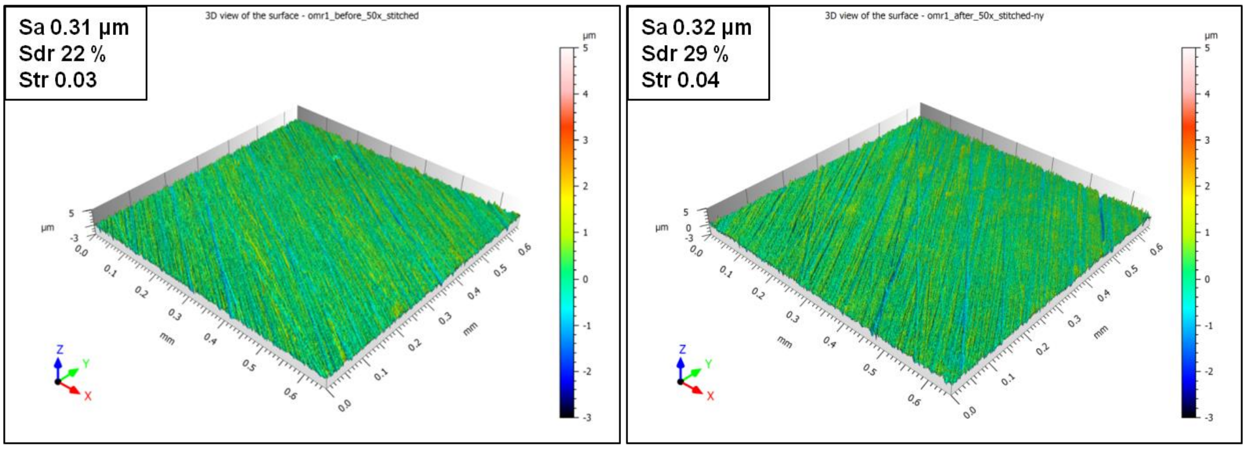

Figure 5. Topography of surface 'Ground' before (left) and after (right) nitrocarburizing, not relocated. Steel 25CrMo4.

3.6. Steel 25CrMo4 rough turned

Before and after heat treatment, see **Figure 6**. Observations:

- Increase in Sdr, more presence of a shorter wavelength texture
- Sa and Str are dominated by machining signature

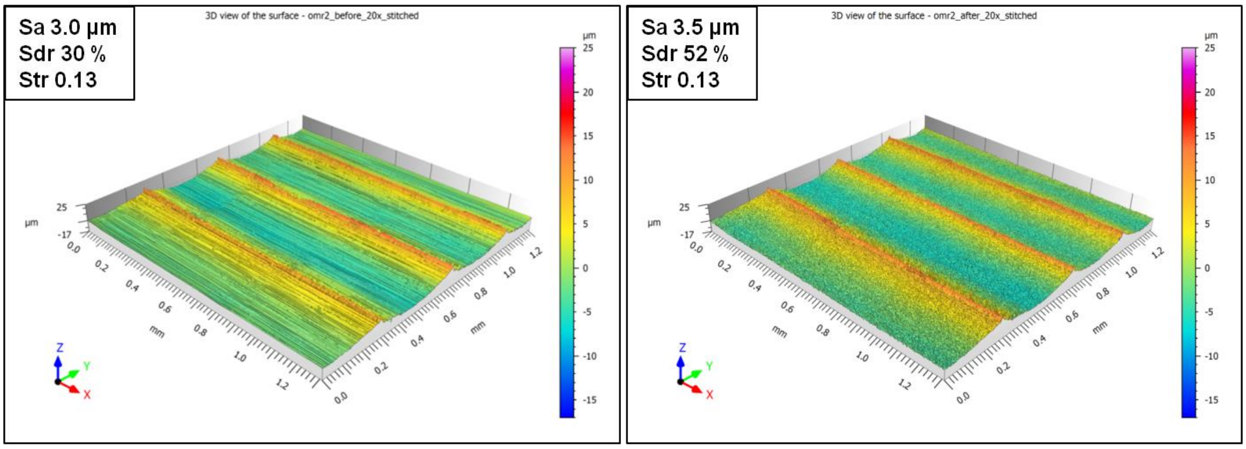

Figure 6. Topography of surface 'Rough turned' before (left) and after (right) nitrocarburizing, not relocated. Steel 25CrMo4.

In **Figure 7** a sub-region of 'Rough turned' is presented. An area between two turning feed ridges have been selected for further study. An additional form removal step has been performed (3'rd order polynomial). Here it can be observed that Sdr and Str has increased and Sa has decreased.

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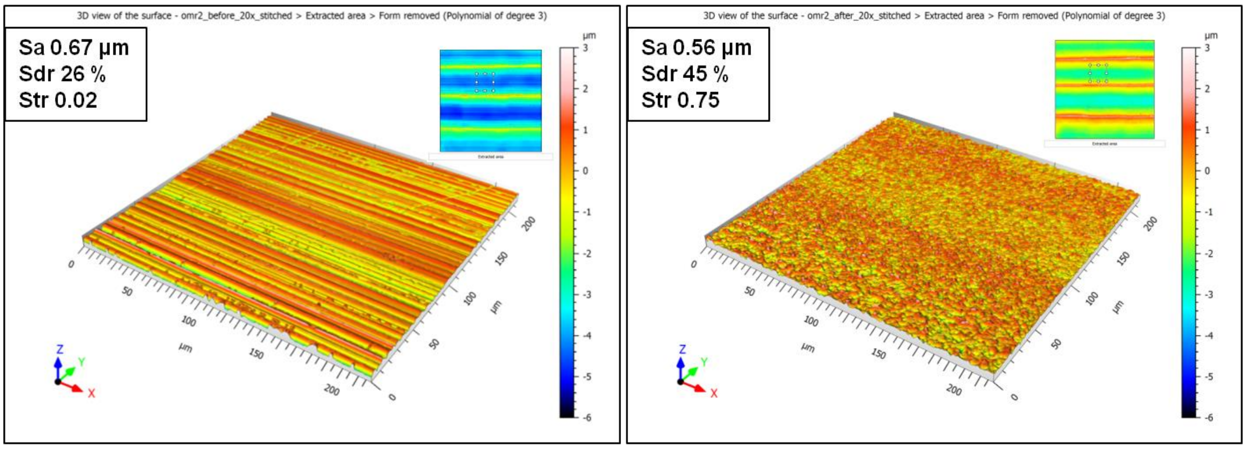

Figure 7. Detail of topography of surface 'Rough turned' before (left) and after (right) nitrocarburizing, not relocated. Additional cropping and form removal (3'rd order polynomial) has been applied. Steel 25CrMo4.

3.7. Steel 25CrMo4 finish turned

Before and after heat treatment, see **Figure 8**. Observations:

- Similar before and after heat treatment
- Sdr has decreased

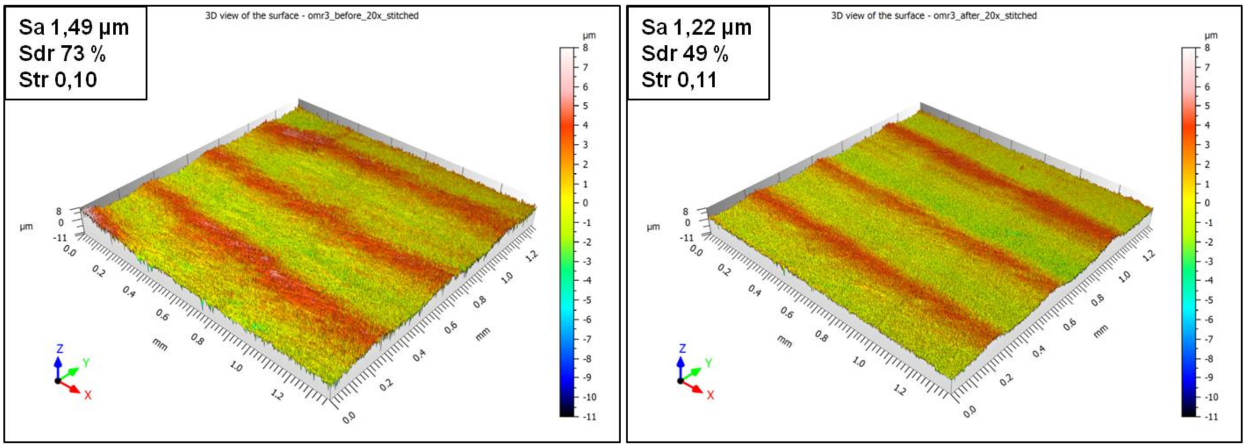

Figure 8. Topography of surface 'Finish turned' before (left) and after (right) nitrocarburizing, not relocated. Steel 25CrMo4.

3.8. Steel 25CrMo4 finish milled

Before and after heat treatment, see **Figure 9**. Observations:

- The surface is rougher after heat treatment, Sa has increased
- Sdr and Str increases
- The anisotropic texture from milling is mixed with an isotropic short wave texture

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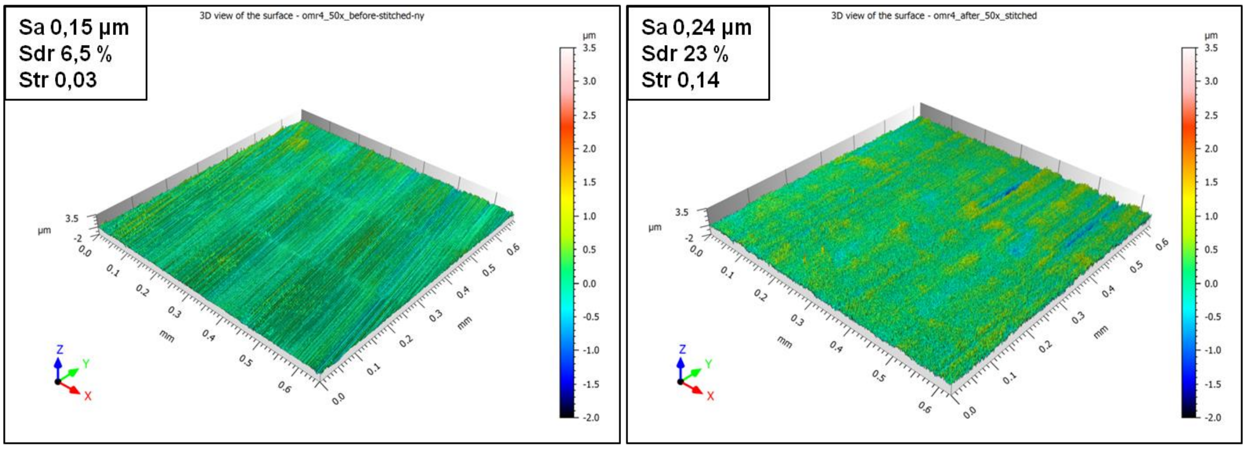

Figure 9. Topography of surface 'Finish milled before (left) and after (right) nitrocarburizing, not relocated. Steel 25CrMo4.

3.9. Steel 25CrMo4 reamed
Before and after heat treatment, see **Figure 10**. Observations:

- The surface is rougher after heat treatment, Sa and Sdr increases.
- Str is low before and after. The surface is dominated by large scratches which are not so much affected by the nitrocarburizing process.

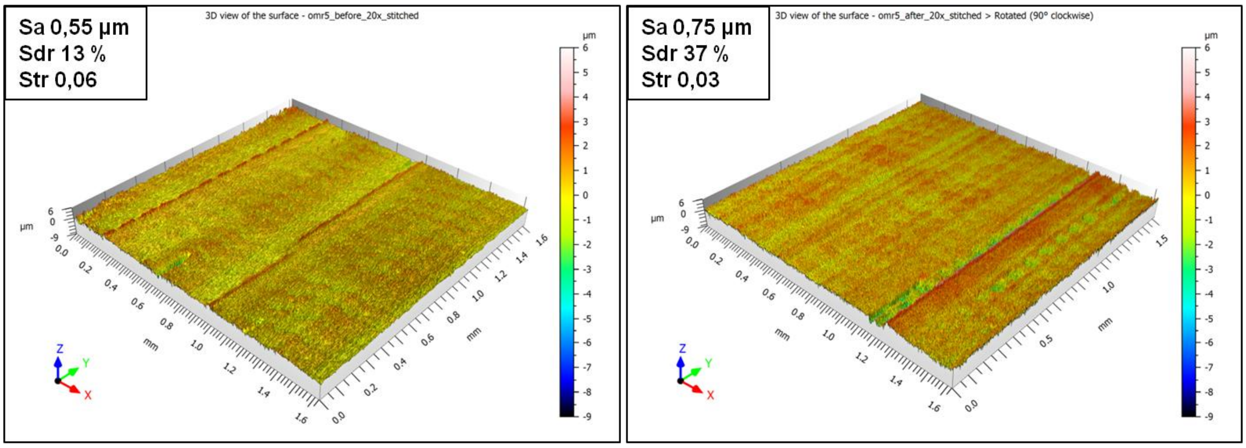

Figure 10. Topography of surface 'Reamed' before (left) and after (right) nitrocarburizing, not relocated. Steel 25CrMo4.

4. Results: Compound layer
For all the surfaces on the component in steel 25CrMo4 the compound layer thickness was 11-12 µm, see **Figure 11** a-e. In this case no effect on the compound layer thickness depending on the surface topography before heat treatment could be noticed. However the final surface topography is influenced by the machining process, e.g. when comparing the ground and rough turned surfaces.

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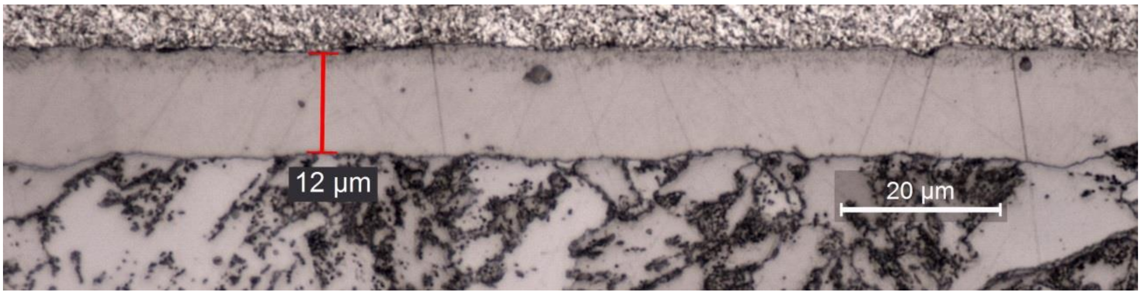
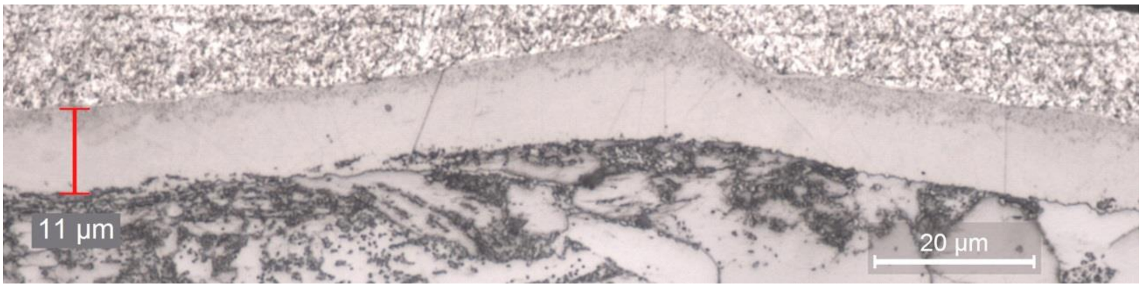
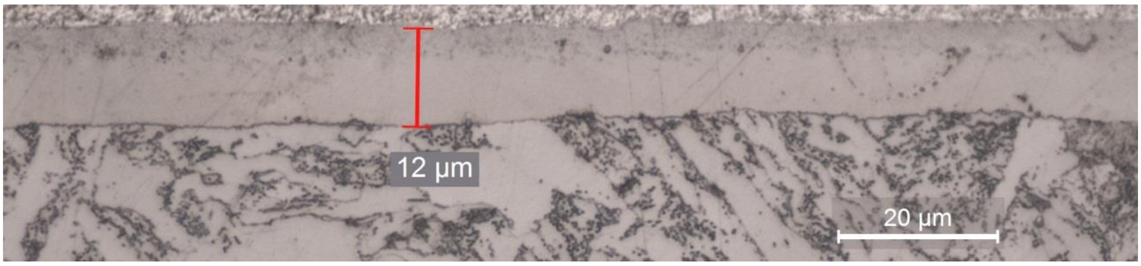


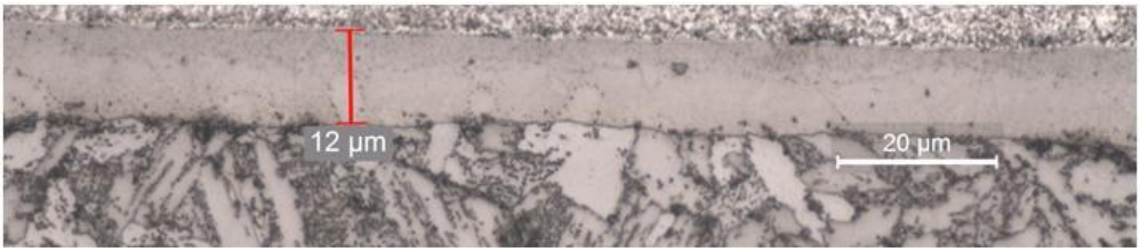
a) Ground



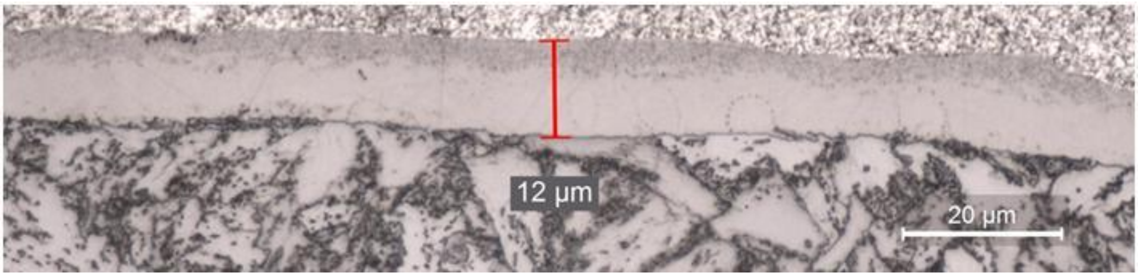
b) Rough turned



c) Finish turned



d) Finish milled



e) Reamed

Figure 11 a-e. Compound layer on surfaces of steel 25CrMo4 for surfaces created with different machining processes after nitrocarburizing, 580°C 150 min.

5. Analysis and discussion

Since the 42CrMo4 surfaces were relocated it was possible to do a precise analysis of the differences before and after nitrocarburizing regarding the surface topography. It was clear that the nitrocarburizing process has an impact on the surface topography. The process creates a short-wave isotropic structure on the original surface and this is particularly evident for the smoother original surfaces (Sa < 0.2 µm). The 25CrMo4 surfaces were not relocated so the exact same areas could not be analysed before and after nitrocarburizing. This makes drawing conclusions more difficult. However, similar tendencies could be observed here as with the 42CrMo4 samples.

For one of the surfaces, Steel 25CrMo4 finish turned, Sdf showed a decrease instead of an increase which was the case for the other surfaces. Also Sa showed a decrease. The reason for the different results for this particular surface is not clear. One uncertainty is the lack of relocation which means that it is not certain that the measurements before and after nitrocarburizing were made in the same location.

No significant effect on the compound layer thickness depending on the surface topography before heat treatment could be noticed. It is possibly due to that the nitrocarburizing time was long enough to enable a stable process and thickness of the layer. The processing parameters were selected to achieve good compound layers. A shorter nitrocarburizing time may have produced samples with differentiated surface properties, both regarding thickness of the compound layer along the surface and the topography. Also, it is possible that initial sample surfaces with more short wavelength texture would react differently to the nitrocarburizing process.

6. Conclusions

- The nitriding processes has an impact on the surface topography, thus the original surface will be affected by the nitrocarburizing.
- A short-wavelength isotropic texture is created on the original surface. Particularly evident for smoother original surfaces (Sdr and Str increases)
- If the original surface is very smooth the surface will be rougher when the short-wavelength texture is created (Sa increases)

7. Acknowledgement

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8. References

[1] T. Holm, P. Olsson, and E. Troell, *Steel and Its Heat Treatment: A Handbook*. SWEREA IVF, 2012.
[2] D. Pye, ‘Nitriding and Nitrocarburizing’, in *Encyclopedia of Tribology*, Springer, Boston, MA, 2013, pp. 2421–2428.
[3] E. Troell, J. Senaneuch, N. Hawsho, and H. Jesperson, ‘Fatigue and wear properties of nitrided steels’, Internal report VBC-R-2013-6, 2013.
[4] J. Vetter, ‘Surface Treatments for Automotive Applications’, in *Coating Technology for Vehicle Applications*, Springer, Cham, 2015, pp. 91–132.
[5] H. Kato, T. S. Eyre, and B. Ralph, ‘Sliding wear characteristics of nitrided steels’, *Surf. Eng.*, vol. 10, no. 1, pp. 65–74, Jan. 1994.
[6] A. Molinari, G. Straffelini, M. Pellizzari, and M. Pirovano, ‘Wear behaviour of diffusion and compound layers in nitrided steels’, *Surf. Eng.*, vol. 14, no. 6, pp. 489–496, Jan. 1998.
[7] T. Bell and D. H. Thomas, ‘Cyclic stressing of gas nitrocarburized low carbon steel’, *Metall. Trans. A*, vol. 10, no. 1, pp. 79–84, Jan. 1979.

[8] M. Emami, H. M. Ghasemi, and J. Rassizadehghani, 'High temperature tribological behaviour of 31CrMoV9 gas nitrided steel', *Surf. Eng.*, vol. 26, no. 3, pp. 168–172, Apr. 2010.
[9] E. Boztepe, A. C. Alves, E. Ariza, L. A. Rocha, N. Cansever, and F. Toptan, 'A comparative investigation of the corrosion and tribocorrosion behaviour of nitrocarburized, gas nitrided, fluidized-bed nitrided, and plasma nitrided plastic mould steel', *Surf. Coat. Technol.*, vol. 334, pp. 116–123, Jan. 2018.
[10] R. Sola, G. Poli, P. Veronesi, and R. Giovanardi, 'Effects of Surface Morphology on the Wear and Corrosion Resistance of Post-Treated Nitrided and Nitrocarburized 42CrMo4 Steel', *Metall. Mater. Trans. A*, vol. 45, no. 6, pp. 2827–2833, Jun. 2014.
[11] P. Cavaliere, A. Perrone, and A. Silvello, 'Multi-objective optimization of steel nitriding', *Eng. Sci. Technol. Int. J.*, vol. 19, no. 1, pp. 292–312, Mar. 2016.
[12] B. Wang, S. Sun, M. Guo, G. Jin, Z. Zhou, and W. Fu, 'Study on pressurized gas nitriding characteristics for steel 38CrMoAlA', *Surf. Coat. Technol.*, vol. 279, pp. 60–64, Oct. 2015.
[13] R. Artigas, 'Imaging Confocal Microscopy', in *Optical Measurement of Surface Topography*, Springer, Berlin, Heidelberg, 2011, pp. 237–286.
[14] the International Organization for Standardization, 'ISO 25178-2:2012 Geometrical product specifications (GPS) — Surface texture: Areal — Part 2: Terms, definitions and surface texture parameters'. 2012.
[15] International Organization for Standardization, 'ISO 4287:1997 - Geometrical Product Specifications (GPS) -- Surface texture: Profile method -- Terms, definitions and surface texture parameters'. International Organization for Standardization, 1997.
[16] F. Blateyron, 'The Areal Field Parameters', in *Characterisation of Areal Surface Texture*, Springer, Berlin, Heidelberg, 2013, pp. 15–43.
[17] Tom R. Thomas, *Rough Surfaces, 2nd Edition*. World Scientific, 1998.
[18] J. Berglund, 'Characterisation of Functional Pressing Die Surfaces', Doctoral Thesis, Chalmers University of Technology, Göteborg, 2011.