COMPARATIVE STUDY OF CHEMICAL-HEAT TREATMENT ON SELECTED CAST HIGH STRENGTH STEELS

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Abstract
The paper deals with some aspect of nitriding and nitrocarburizing of two middle alloyed high strength steels. Theoretical part very briefly describes fundamentals and benefits of mentioned chemical-heat treatments. Experimental part is focused on hardness profile measurement and depth layer evaluation along with microstructure study of basic areas of layer. Results from experimental part of the paper allow to increase utility properties of castings.

Keywords: high strength, microhardness, nitridizing, nitrocarburizing, layer, microstructure

1 Introduction

Cast steels are characterized by a relative higher carbon content and more coarse-grained microstructure in comparison with constructional steels. The higher carbon content is needed to provide good casting properties like fluidity and viscosity, which allows an effective application of the casting process. Due to more coarse-grained structure, casting steel has lower values of mechanical properties in comparison with equal constructional steels [1].

The forging process produces a part that is anisotropic. This means that the mechanical properties of a forging are better in the longitudinal direction (parallel to lines of flow) versus the transverse direction (perpendicular to lies of flow). Conversely, a casting is homogeneous; this means that the mechanical properties of a casting are the same, regardless of the orientation of test bar material [2].

The object of presented study is the casting of complex shape made by middle alloyed high strength steel applied as an element of additional armour protection for mobile vehicles [1]. Complex shapes of the castings do not allow applying hardening mechanism based on deformation processes as are forging or rolling. Therefore, some of chemical-heat processes are very beneficial to improve mechanical properties of castings (hardness mainly) besides conventional heat treatment (quenching and tempering).

2 Fundamentals of nitriding and nitrocarburizing

The nitriding process typically involves the introduction of nitrogen into the surface adjacent zone of a component, usually at a temperature between 500 and 580 °C. Depending on the nitriding “power” of the nitriding atmosphere surrounding the component, a nitrided zone emerges that, especially in the case of ferritic iron-base alloys or ferritic steels nitrided at temperatures lower than 590 °C, can be subdivided into (Fig. 1) [3]:

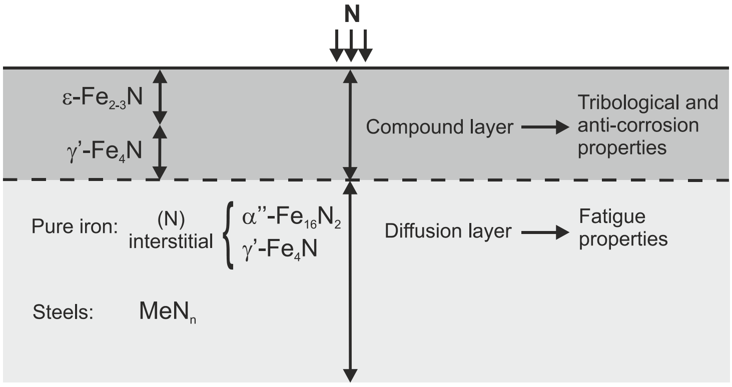


Fig.1 Schematic cross section of nitrided region of an steel [3]

- A compound layer (of thickness, say, up to several 10 mm), largely composed of iron nitrides, as γ-Fe$_4$N$_{1-x}$ and ε-Fe2N$_{1-x}$
- A diffusion zone (of thickness, say, up to several 100 mm), where, in the case of pure iron or carbon steel, after nitriding, upon either slowly cooling or upon aging subsequent to quenching, the nitrogen dissolved at the nitriding temperature precipitates as iron nitrides in the diffusion zone, or, in the case of steel containing

alloying elements with affinity for nitrogen, as aluminium and chromium, alloying element nitrides precipitate during nitriding

The technological importance of nitriding is derived from the pronounced increase of the resistances against fatigue, wear, and corrosion, which can be achieved by tuned applications of the nitriding process.

Nitrocarburizing process is similar to gas carburization with the addition of ammonia to the carburizing atmosphere, which provides a source of nitrogen. Nitrogen is absorbed at the surface and diffuses into the workpiece along with carbon. Nitrocarburizing (around 850 °C) is carried out at temperatures substantially higher than plain nitriding (around 530 °C) but slightly lower than those used for carburizing (around 950 °C) and for shorter times. Nitrocarburizing tends to be more economical than carburizing, and also reduces distortion during quenching. The lower temperature allows oil quenching, or even gas quenching with a protective atmosphere [3, 4].

Nitrocarburizing forms a hard, wear-resistant case, is typically 0.07 mm to 0.5 mm thick, and generally has higher hardness than a carburized case. Case depth is tailored to the application; a thicker case increases the wear life of the part. Nitrocarburizing alters only the top layers of the workpiece; and does not deposit an additional layer, so the process does not significantly alter the dimensions of the part.

3 Materials and methods

The experimental elements are casting made with using investment casting process by two middle alloyed high strength steels 40CrNiMo4 and 27MnCrV4. Basic chemical composition and average values of basic mechanical properties after quenching and tempering are shown in table 1.

Table 1 Basic chemical composition and mechanical properties of experimental steels (in quenched state)

27MnCrV4	**Element**	**C**	**Mn**	**Si**	**Cr**	**Mo**	**Ni**	**V**	**Ti**	**P**	**S**	**Fe**
	[wt. %]	0,3782	1,47	0,54	0,807	0,577	0,0969	0,3435	0,0027	0,0265	0,0203	95,3
	R_m [MPa]		1300÷1600		$R_{p0,2}$ [MPa]		950		HV [-]		340÷390	
40CrNiMo4	**Element**	**C**	**Mn**	**Si**	**Cr**	**Mo**	**Ni**	**V**	**Ti**	**P**	**S**	**Fe**
	[wt. %]	0,4308	0,897	0,583	0,891	0,448	1,84	0,0175	0,0017	0,0242	0,0191	94,3
	R_m [MPa]		1000÷1300		$R_{p0,2}$ [MPa]		1030		HV [-]		345÷395	

Two types of chemical-heat treatment were applied on experimental samples. The samples assigned to nitridizing were quenched from austenitization temperature 850°C in oil (120°C) and then tempered (460°C / 2 h) a(460°C / 2 h)nd cooled on air. As final step, nitridizing was applied at temperature 505°C / 12h.

The samples assigned to nitrocarburizing were nitrocarburized first at 860°C / 10 h, then quenched in oil (120°C) and finally tempered (450°C / 2 h) and cooled on air.

Four groups of experimental samples were prepared by this treatment, nitrided and nitrocaburized samples for both 27MnCrV4 and 4CrNiMo4 materials.

The course of micro hardness HV0, 5 across nitridizing and nitrocarburizing layers was measured on these samples where Vickers hardness test is performed with low load (4, 9 N) in accordance with EN ISO 6507 standard. The values from micro hardness course are also used to calculate the layer depth (Nht) according to DIN 50190. Finally, surface hardness of nitride samples was measured by Vickers test with the load of 49 N.

Second step of experimental procedure was investigations of both niridizing and nitrocarburizing layers microstructure by optical microscopy.

4 Hardness profile of chemical-heat treatment layers

Micro hardness HV0, 5 profile curves for both investigated materials and their chemical-heat treatments variations are shown in fig. 2 and fig. 3. The depths of particular layers determined according to DIN 50190 (in table 2) correspond with the fundamentals of used chemical-heat processes.

Table 2 Layer depth Nht [mm] according to DIN 50190

Nht [mm]	Nitridizing	Nitrocarburizing
27MnCrV4	0,25	1,2
40CrNiMo4	0,2	1,3

The course of microhardness in nitriding layer is very similar for both materials. It is high in the begging (close to surface) and then falls almost to values of hardness of basic material in range of 0,1÷0,2 mm. In a case of nitrocarburizing, microhardness is decreasing very slowly and it reaches values of basic material in about 1, 2÷1,4 mm.

Surface hardness after nitridizing in compare with hardness values reached for nitrocarburizing is higher for 27MnCrV4 steel. In a case of 40CrNiMo4, opposite values were measured, surface hardness after nitrocarburizing is higher than hardness after nitridizing. The reason is higher content of carbon in 40CrNiMo4 which causes higher hardness values after quenching as final phase of nitrocarburizing.

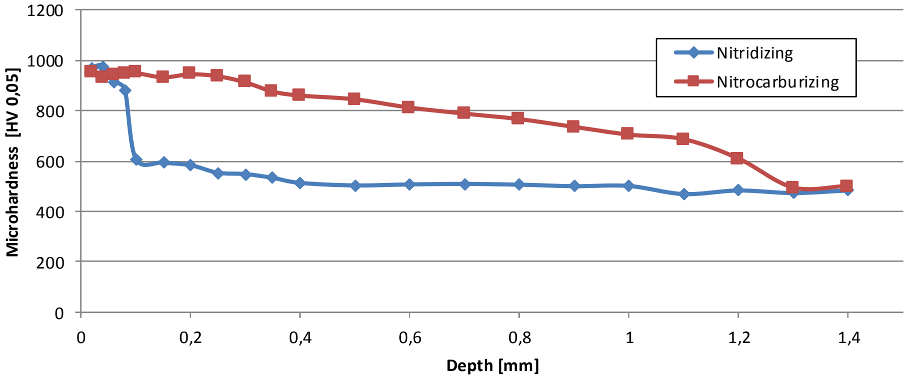


Fig. 2 Hardness HV,5 profile for 27MnCrV4

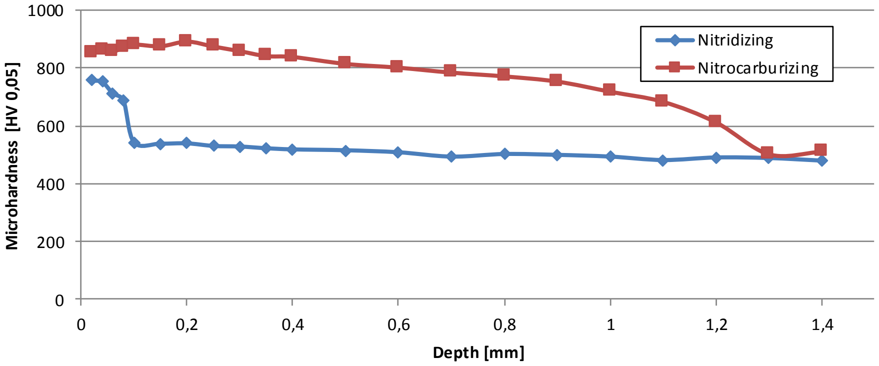


Fig. 3 Hardness HV,5 profile for 40CrNiMo4

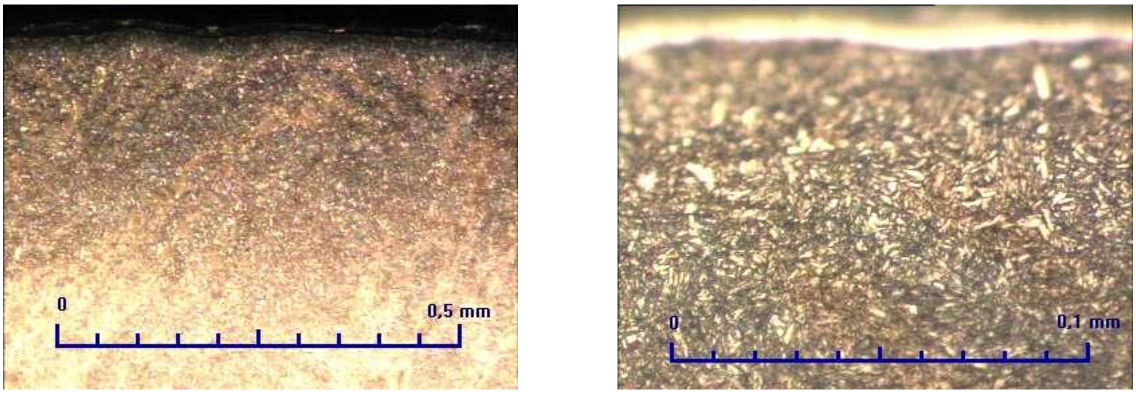
5 Microstructure investigation

The microstructure after nitridizing of experimental samples is documented on photographs in fig. 4 and fig. 5. Nitridizing layer is shown there with two different magnifications. Phase γ’ is not even visible with magnification 500x. Phase ε (white or compound layer) is compact but with no constant depth in range 4÷15 μm.

Soft carbidic particle and dark sature sorbite are observable flowing to light sorbite of origin quenched and tempered microstructure.

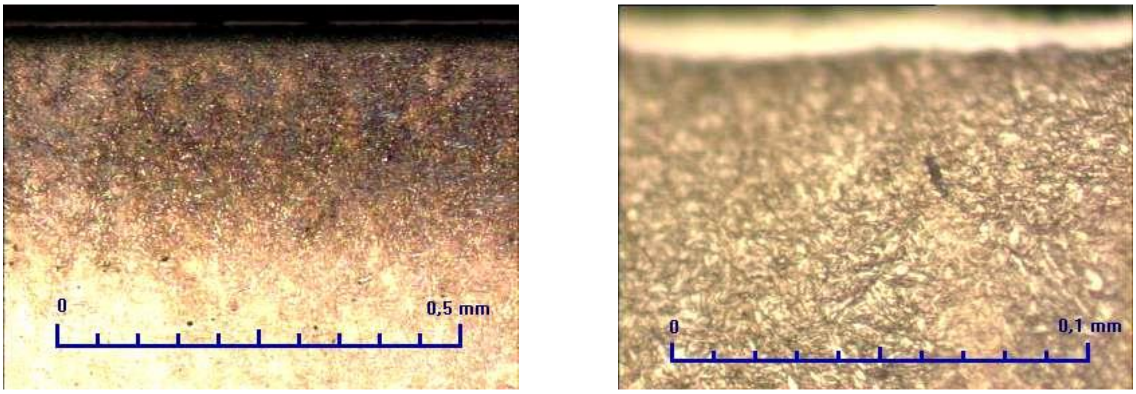
The microstructure after nitrocarburizing of experimental samples is documented on photographs in fig. 6 and fig. 7 for both investigated materials. The strip of carbides was observed close below surface in both cases. The reason is high content of carbon of used materials. Positive effect of this occurrence is high surface hardness confirmed in microhardness profile measurement too. On the contrary, the presence of carbides makes the layer brittle and less resistant against wear.

Basic area of nitrocarburizing layer consisting of strip with coarse martensitic needles and retained austenite is documented on fig. 5c and fig. 5d.



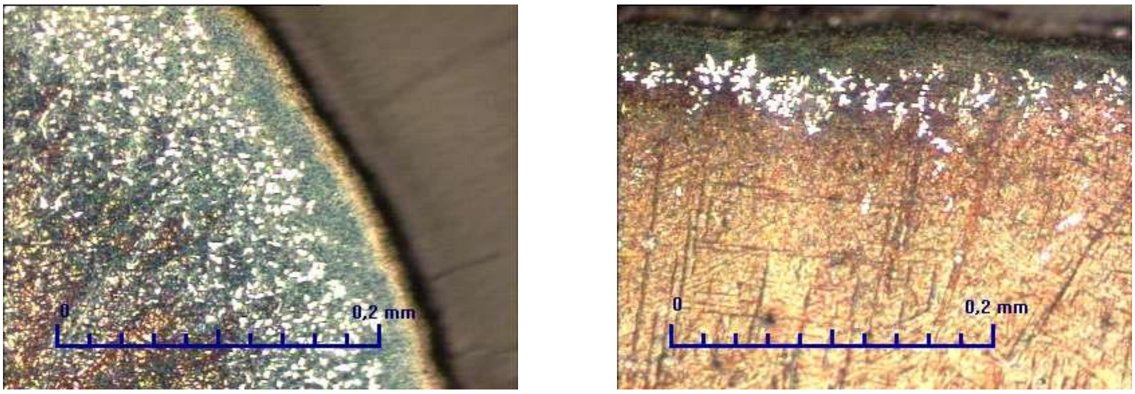
a) b)

Fig. 4 Microstructure of nitridizing samples of material 40CrNiMo4
a) mg. 100x, nitridizing layer 100x; b) surface with nitridizing layer beginning, mg. 500x



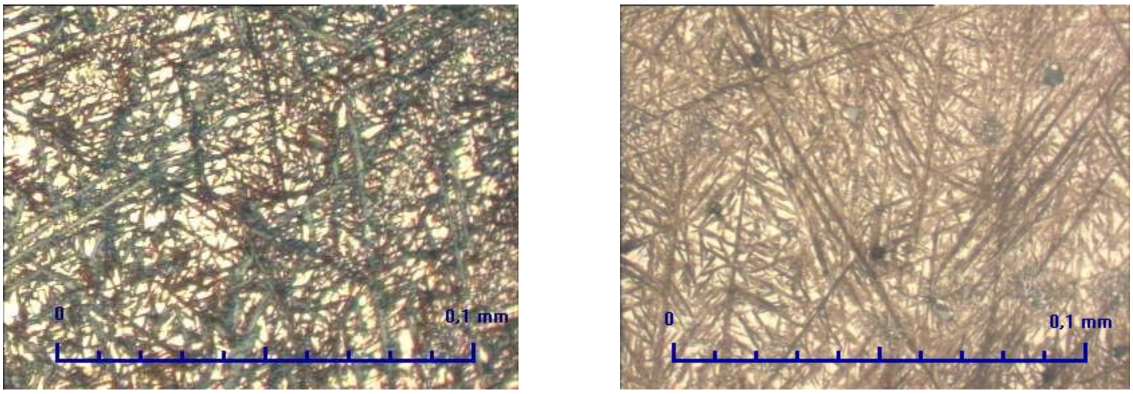
a) b)

Fig. 5 Microstructure of nitridizing samples of material 27MnCrV4
a) mg. 100x, nitridizing layer 100x; b) surface with nitridizing layer beginning, mg. 500x



a) b)

Fig. 6 Beginning of nitrocarburizing layer with carbide strips
a) mat. 40CrNiMo4, mg. 200x; b), mat. 27MnCrV4, mg. 200x



a) b)

Fig. 7 Part of nitrocarburizing layer layer
a), mat. 40CrNiMo4, mg. 500x; d) mat. 27MnCrV4; mg. 500x

6 Conclusions

Nitridizing and Nitrocarburizing were applied on two casting steels 40CrNiMo4 and 27MnCrV4. Steel 27MnCrV4 reched relative higher values of hardness after nitridizing than 40CrNiMo4 and higher values were reched by nitridizing in compare to hardness after nitrocarburizing of that steel. However, Steel 27MnCrV4 reached higher value of hardness after nitrocarburizing due to higher carbon content. The carbon content causes carbide strip creation just below the surface.

Both investigated steels are very suitable for treatment by nitridizing to increase their surface hardness, wear resistance, corrosion resistance and fatigue resistance. Results achieved form nitrocarburizing are satisfactory, but problematic in a view of nitrocarburizing layer microstructure. Carbides observed in the layer could cause its brittleness and this is also one of goals to next research.

References

[1] BARÉNYI, I.: *Dissertation thesis*, .TnU AD, Trenčín, 2008, (in Slovak)

[2] ZWIRLEIN, T.: *Comparing Castings and Forgings*, [online] , Available on: http://www.gearsolutions.com/article/detail/5388/comparing-castings-and-forgings [cited 30.11.2015]

[3] MITTEMEIJER, E.J.: *Fundamentals of Nitriding and Nitrocarburizing*. ASM Handbook, Volume 4A, Steel Heat Treating Fundamentals and Processes, 2013

[4] HOLM, T, SPROGE, L.: *Nitriding and Nitrocarburizing*. Ferronova, 2015. [online] Available on: https://www.ferronova.com/international/web/lg/fer/likelgfer.nsf/repositorybyalias/training_nitr/$file/Nitr3.pdf [cited 30.11.2015]

[5] PYE, D.: *Practical Nitriding and Ferritic Nitrocarburizing*, ASM International, 2003