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MODERN CARBURISING AND HARDENING TREATMENTS OF TRANSMISSION COMPONENTS

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ABSTRACT
The performance of the carburised and hardened gear depends on several variables. Vacuum carburising will provide high quality well controlled case for deep hardenable steels. Combined carburising and carbonitriding can be used for thick hardened cases with nitrogen in the surface layer for better pitting and wear resistance.
Keywords: carburising, vacuum carburising, carbonitriding, gas quenching

1. INTRODUCTION
The performance of the components depends on the carbon content, grain size, retained austenite and carbides of the case, and residual stress level [1]. High hardness and minimum retained austenite are essential and small evenly distributed spheroidised carbides in a fine martensitic matrix beneficial for high wear and scuffing resistance. In conditions of severe impact wear high carbon may lead to chipping, and low to wear and plastic deformation and surface breaking. High bending fatigue strength requires ductility and toughness, fine martensitic microstructure without carbides, and low amount of retained austenite. The surface carbon content and the case hardness must be limited. High contact fatigue resistance will be achieved with limited amount of carbides and retained austenite, both finely dispersed in the matrix. Nitrogen and nitrides in the surface layer improve load carrying capacity providing high contact fatigue resistance, wear resistance and impact strength. The compressive residual stresses are also high.

Carburising in gas atmosphere furnace cause always internal oxidation of the steel surface and non-martensitic microstructure. In vacuum carburising, where the parts are carburised in a partial pressure of hydrocarbon gas without oxygen, internal oxidation will be prevented [2,3,4]. Vacuum carburising can offer improved mechanical properties due to the lack of inter-granular oxidation. Depletion of manganese may take place in the surface layer [5]. Like internal oxidation, the manganese depletion lowers the hardenability encouraging non-martensitic structure in the surface layer especially in gas quenching. In both gas carburising and vacuum carburising atmosphere, ammonia can be added for carbonitriding. Combined carburising and carbonitriding will result in deeper cases with better engineering performance than would be achieved by carburising alone. High-pressure gas quenching with 10 - 20 bar nitrogen or helium is gaining more and more interest. Gas quenching is ideal for light loads, thin sections, and moderate-to-highly alloyed steels. Gas quenching provides smooth and uniform cooling thus minimising distortion and results in a uniform case depth [6].

2. EXPERIMENTAL

Steels in Table 1 were vacuum carburised with acetylene (C_2H_2) at 930°C to have surface hardness of 700HV and case depth of 1mm. Test pieces were 100mm long round steel bars with 20 and 80mm diameters. The grades 20NiMoCr2-2, 20MnCr5 and 18CrNiMo7-6 are common carburising steels with different hardenability. Imaform CF is a boron alloyed low carbon steel grade designed to cold forging. Quenching was in 10bar nitrogen. Parts were tempered at 180°C for 2 hours. Surface hardness profiles were measured using Vickers test method (HV1), microstructures examined by optical microscope and alloying element concentration profiles measured using glow discharge optical emission spectroscopy (GDOES).

Table 1. The melt analysis of the steels used in vacuum carburising tests.

Alloying element, w. %	20NiMoCr2-2	20MnCr5	18CrNiMo7-6	Imaform CF
C	0.21	0.19	0.18	0.08
Mn	0.85	1.26	0.74	0.70
Cr	0.56	1.07	1.70	1.50
Ni	0.43	0.10	1.48	0.13
Mo	0.17	0.02	0.27	0.06
Si	0.25	0.29	0.27	0.18
B				0.003

Test pieces of ∅60 x 15mm from the steel 20MnCr5 and ∅70 x 15mm from the steel 18CrNiMo7-6 were carburised and carbonitrided in a fluidised bed. Nitrogen was used in heating-up, diffusion and furnace cooling stages, air and propane (4.5:1) for pulse carburising, and air, propane (4.5:1) and ammonia (15%) in carbonitriding. The carbon and nitrogen contents of the samples were controlled by boost of 15 and 30 minutes and diffusion of 30 and 60 minutes. The process was carburising at 950°C, cooling down to 840°C with the furnace in 30 minutes, carbonitriding at 840°C, quenching in oil bath at 60°C. Some samples were re-hardened with austenitising at 840°C for 20 minutes in fluidised bed in nitrogen and oil quenching. All samples were tempered two hours at 180°C. The microstructure of the samples was examined and the surface hardness profiles were measured. Carbon and nitrogen profiles were determined by milling the case in successive layers of 0.1mm thick and analysing the chips with Leco CS 444-LS analyser.

3. RESULTS

3.1. Vacuum carburising and gas quenching

All steels had fully martensitic microstructure with the exception of 20NiMoCr2-2 whose case contained also bainite. The measured surface hardness profiles are shown in Figure 1. Measured alloying element concentration profiles for 18CrNiMo7-6 are shown in Figure 2, where the weight percentages are multiplied by 100 with the exception of Cr and Ni which are multiplied by 10.

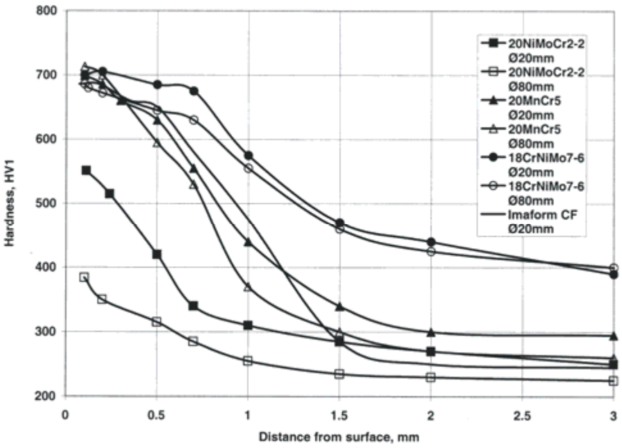

Figure 1. Surface hardness profiles for vacuum carburised samples.

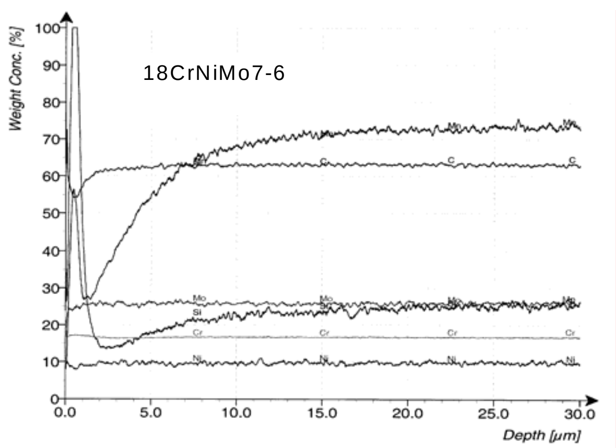

Figure 2. Alloying element concentration depth profile for vacuum carburised 18CrNiMo7-6.

3.2. Carburising and carbonitriding

The boost period of 30 minutes resulted in globular carbides in the steel surface. No carbides formed with the 15 minutes boost. Diffusion of 30 minutes after the boost resulted in surface carbon of 0.75% and 60 minutes in 0.68%. The carbonitriding of 840°C/1h resulted in nitrogen content of 0.35 - 0.40% and nitriding depth of 0.35mm. Direct quenching prevented the formation of grain boundary carbides and nitrides, but resulted in microstructure containing even from 60% to 90% of retained austenite. Re-hardening eliminated the austenite. In Figure 3 the hardness profiles of 20MnCr5 samples can be seen. The steel grades used had the same kind of carbon and nitrogen contents and hardness values.

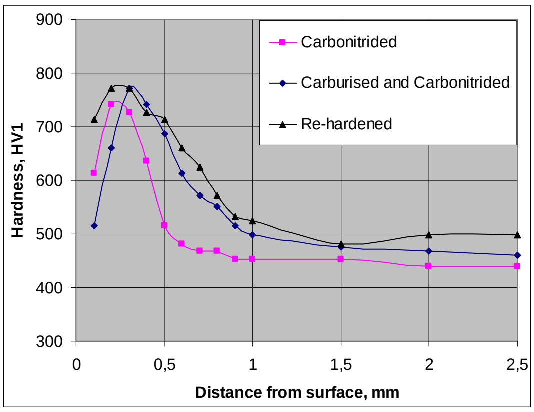

Figure 3. Hardness of quenched and tempered 20MnCr5 after carbonitriding (840°C/2h), carburising and carbonitriding (15min boost and 60min diffusion at 950°C, and carbonitriding of 840°C/2h), and re-austenitising (840°C/20min in nitrogen). Quenching was in oil at 60 °C and tempering 180°C/2h.

4. DISCUSSION

Gas quenching demands deep hardening steel as can be seen in Figure 1. Low alloyed carburising steel 20NiMoCr2-2 did not achieve fully martensitic case microstructure as did steels with greater amounts of Cr and Ni and this resulted in poor hardness values and profiles. High Cr-content along with Ni alloying (18CrNiMo7-6) resulted in the highest case depth. If the size and mass of carburised part is increased, proper alloying becomes even more crucial according to the hardness profiles of test pieces with 20 and 80mm diameters. Also, it should be noted that low carbon Imaform CF had adequate surface hardness and case depth which is due to its high Cr-content and B-alloying.

Loss of Mn and Si was observed in the surface layers of all test steels. Especially Mn seems quite eager to vaporise in vacuum as has been reported elsewhere [5]. Loss of Mn can lower the hardenability of steel near the surface and result in non-martensitic structures. This may for its part have adverse effects on compressive residual stresses and fatigue resistance. Nevertheless, because carburised transmission parts such as gears are often grinded after heat treatment, this depleted zone is more or less removed. Loss of Si was more unexpected because it has not been mentioned before. Perhaps it may be related to the surface oxidation which is discussed later, because Si is the most easily oxidizing alloying element in steel. Further study could be practicable to clarify under which conditions alloying elements tend to vaporize in vacuum and what kind of effects this phenomenon has on the performance of transmission gears.

Mn and Si-concentration peaks were observed less than 2µm below the surface. After additional measurements oxygen peaks were detected in same positions, so therefore it can be presumed that these peaks were caused by surface oxidation. However, it is still unclear what has caused the oxidation. Tempering temperature was quite low (180°C) so it is unlikely that it could be the cause. Also, carburising was carried out in vacuum. One possible explanation could be that during the heat-up stage convection was used to speed up the temperature rise and this has resulted in this minor oxidation.

The carburising in fluidised bed at 950°C with air-propane 4.5:1 is effective. The boost period of 30 minutes is too long and 15 minutes the proper time to carburise the steel surface to the saturation value of carbon without forming carbides. Diffusion of 30 minutes or longer after the boost will control the surface carbon content. The diffusion time and carbon content must be selected according the steel grade. The steel grades examined are very similar in carburising and nitriding behaviour in the conditions examined.

The nitrogen content of the surface does not become excessive high in fluidised bed carbonitriding in spite of the high ammonia content. The decomposition rate of the ammonia is presumably faster in the fluidised bed conditions than in atmosphere furnaces.

The combined carburising and carbonitriding will result in high retained austenite content in direct quenching. Re-hardening must be used to have qualified microstructure and hardness values. Quenching from the carbonitriding temperature, instead of slow cooling, will be needed for fine carbide and nitride precipitation in the final re-hardened component. The examined steels will case harden to depth of 0.8mm in the combined carburising and carbonitriding in fluidised bed in 1.25 hour carburising at 950°C and two hours carbonitriding at 840°C.

5. CONCLUSIONS

The performance of the transmission components requires optimised carburising and hardening process in the respect of the case microstructure, carbon content and gradient. Modern vacuum carburising and gas quenching can very well fulfil these demands. The hardenability of carburising steels must meet the demands of gas quenching. Despite the lack of internal oxidation in vacuum carburising there are still some other aspects that may have negative effects on mechanical properties. Loss of alloying elements such as Mn is the most significant. Nitrogen and nitride precipitation will enhance wear resistance and contact fatigue strength. Combined carburising and carbonitriding will provide deep case with nitrogen alloyed surface layer. To ensure fine dispersion of nitrides and carbides and to avoid excess retained austenite, direct quenching from the carbonitriding temperature and re-hardening are suggested according to the experimental of this research.

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