

# Is substituting case hardening with nitriding possible for components susceptible to distortion?

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**Introduction.** The question serving as the title of this paper cannot be answered to any satisfactory degree without extensive analyses aimed in particular at the specific service properties of the components that are to undergo heat treatment.

Owing to customers' increasing demands for heat treatment that does not involve subsequent machining or causes only minimal changes in the component's final dimensions, job heat treatment providers are seeing themselves confronted more and more frequently with this very question. The decisive incentive is supplied by the superior, repeatedly documented results obtained from nitriding and nitrocarburising, which cause less changes in dimensions and shape when compared directly with case hardening and carbonitriding.

**Changes in dimensions and shape during heat treatment.** It must first be emphasised here that during heat treatment components undergo not only the desired modifications to their specific material and/or design properties, but also changes to virtually all of their dimensions, including their shape. Case hardening and nitriding are

no exceptions. Internal stress conditions give rise to deviations from the target geometry.

In summary, these deviations are assessed negatively as distortion and, in mass production, pose a decisive problem that throughout the world is the cause of the highest additional costs over the entire production cycle.

And if these changes in dimensions and shape are assessed in connection with a heat treatment, then the heat treatment providers are generally seen, even today, as having the overall responsibility.

Although this is known to be unjust, there is often little understanding. Many activities in the USA and, recently, in Germany as well are targeting an overall solution to this problem. One approach is seen in the evaluation of and consideration to the changes in dimensions and shape as a "system property", in other words the control of heat processes must be regarded as a complex technological field involving all aspects of material, production, and heat treatment technologies. This also applies to the question whether and

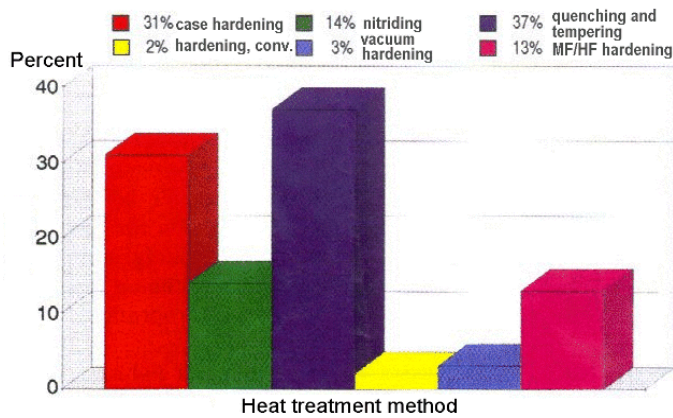
**Summary.** For the purpose of minimising changes in dimensions and shape, nitriding cannot replace case hardening until the respective component has first been analysed and, if necessary, supplementary field trials have been conducted as well. Two examples taken from practice show that this substitution is in fact possible. Promising results are obtained when there is close cooperation between the manufacturer of the component, the materials expert, and the heat treatment provider.

when substituting case hardening and carbonitriding with nitriding and nitrocarburising can give rise to promising results for workpieces susceptible to distortion. What is needed for a qualified decision here is knowledge of the crucial parameters causing distortion in each case and how these can be influenced by the substituting method to yield positive results.

## Case hardening and carbonitriding.

In the metal-processing industries, case hardening has been for many years the predominant heat treatment method for enhancing the functional and service properties of highly stressed components in the construction of automobiles, gears, engines, and machinery. **Figure 1** shows that 31% of the entire hardening throughput at the Härtereie Reese Weimar in the year 2000 underwent the methods of case hardening and carbonitriding. This also agrees with the estimates of Edenhofer [1], according to which case hardening today makes up approximately one third of the world market share of all heat treatment hardening processes.

The process technology involves the targeted enrichment of carbon (case



**Figure 1.** Throughput of hardening stock at Härtereie Reese Weimar for the year 2000, based on heat treatment methods

hardening) or of carbon and nitrogen (carbonitriding) in the component's surface to generate a hardenable surface layer. The active process runs above the  $A_1$  temperature. The required martensite surface layer is then generated after the subsequent quenching of the workpiece at a supercritical rate from the austenite phase. This sequence of operations gives rise to changes in the dimensions and shapes of case-hardened components that in general entail subsequent machining.

The quality parameters in case hardening are the surface hardness and the case depth (CD). In practice, there are no restrictions on the technical realisability of case depths from 0.4 to 3 mm. In the case of case depths greater than 3 mm, process restrictions must be taken into account. The hardness increase in the case depth, whose value can be varied with tempering, and the build-up of internal compressive stresses in the surface layer increase the resistance to abrasion and fatigue as well as the dynamic strength. The CD required for the respective application is essentially defined by the loads expected to act on the surface of the workpiece. In the case of wearing by rolling, the CD should be slightly deeper than the point in the surface layer at which the shear stress maximum is generated by the applied loading. For gearwheels, determining the CD is generally based on the module [2]. The optimal fatigue strength is obtained when the CD is about 15 to 20% of the component's decisive cross section.

In the end, it is the concentration of carbon in the surface layer and the hardenability of the base metal that define the hardness shape in the surface layer. This must be noted in particular when high core strengths are demanded. Suitable steels for case hardening and carbonitriding are listed in DIN 17210.

**Nitriding and nitrocarburising.** These methods have undergone a rapid development over the last twenty years.

One particular cause is that the introduction of nitrocarburising in industry no longer requires special nitriding steels as listed under DIN 17211. Now, almost all ferrous materials are suitable for nitriding and nitrocarburising. Even lamellar and spheroidal graphite cast iron are nitrided and nitrocarburised with success.

As shown in **Figure 1**, the year 2000 saw 14% of Härtereie Reese Weimar's throughput of hardening stock undergo gas nitriding and gas nitrocarburising. The range of parts for hardening supports the conclusion that, compared with case hardening and other surface layer technologies, nitriding is possible for a relatively wide range of applications as a result of the specific structure of nitrided surface layers. Typical applications are gear and engine parts for the automobile industries; drive mechanisms for gear manufacturing; spindles and other wearing parts for general machine construction and precision engineering; cold and hot forming tools; and tools for the plastics industries.

The technology behind nitriding / nitrocarburising involves enriching the surface of the workpiece with nitrogen / nitrogen and carbon at temperatures between 490 and 580 °C. This gives rise to a composite whose properties are defined by the nitrided or nitrocarburised case in conjunction with the base metal. The case is generally made up of a surface zone exhibiting a different metal grid, the compound layer (0 to 30 µm thick), and a diffusion zone with an unchanged metal grid. The compound layer consists of iron nitride, iron carbonitride, and cementite (for steels alloyed with nitrides and carbonitrides) and a porous structure close to the surface. This layer is supported by the diffusion zone originating from the base metal and created by the process of precipitation hardening. The diffusion layer in turn consists of nitrides, carbonitrides, secondary cementite, and dissolved nitrogen. In practice, diffusion zones with thicknesses ranging from 0.2 to

1.2 mm are usual. Quality factors are the hardness, thickness, and structure of the compound layer (CL) as well as the hardness and thickness of the diffusion zone. The parameters important for the official acceptance are in general only the surface hardness (HV1 / HV5), the depth of nitriding (DN) in accordance with DIN 50190 (Part 3), and in exceptional cases the thickness of the compound layer, whose hardness can be as high as 1200 HV0.01. Depending on the selected matrix and its heat-treated state, hardnesses ranging from 350 to 1100 HV1 can be obtained in the diffusion zone. This two-layer structure of the nitrided case gives rise to properties that exert many positive influences on the serviceability of nitrided components. For example, tribological and chemical service properties are influenced primarily by the thickness and structure of the compound layer, and the enhanced thermal, mechanical, and cyclical resistance of nitrided components originate primarily from the diffusion zone created by the process of precipitation hardening as mentioned above. One negative aspect is the relatively high brittleness of the compound layer. Flaking, chipping, even breakage can be the consequence. This places limits on the possible applications, above all where the component is subjected to dynamic loading and high surface pressure.

The structure of the compound layer and the depth of nitriding must be adjusted to the required service values, analogously to case hardening. Here too, defining the depths of nitriding must be based, for example in the case of gears, on the module. So that the case cannot break away, the shear stress maximum generated under load must always lie inside the nitrided case.

The relatively low changes to dimensions and shape with all nitriding methods are essentially based on the treatment of the components below the  $A_1$  temperature. **Figure 2** shows a process-controlled shaft furnace complex for gas nitriding and gas carbonitriding at Härtereie Reese Weimar.

**Where substituting case hardening with nitriding is possible for components susceptible to distortion.**

If the intention is to reduce changes to dimensions and shape brought about by thermochemical surface hardening methods, then the course of treatment below the  $A_1$  temperature, i.e. without phase transformation, makes nitriding the obvious choice over case hardening. Yet if the intention is to substitute case hardening with a nitride treatment for components susceptible to



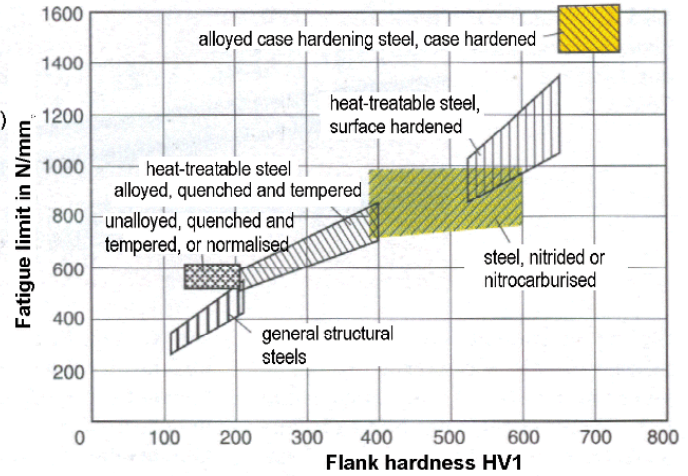
**Figure 2.** Process-controlled 1500 x 2000 shaft furnace complex for gas nitriding and gas nitrocarburising at Härtereie Reese Weimar

distortion then it is imperative that the component's specific service properties are thoroughly analysed. In cases of doubt, field trials must also be conducted. One useful aid in deciding on suitable materials and their heat treatment for the manufacture of highly stressed gear components is to draw up approximate values for obtainable fatigue strengths as a function of cylindrical and bevel gear flank hardnesses under DIN 3990 (**Figure 3**). Here, case-hardened components demonstrate their superiority over nitrided or carbonitrided ones. In addition, the improvement to the fatigue strength obtained with a nitriding method is clearly better than with quenching and subsequent tempering.

In many cases, the required core strength of the components is decisive for the conversion from case hardening to nitriding. Here, the temperature-time sequence needed for the nitriding method often presents a handicap to a successful substitution to the effect that the required core strength can no longer be maintained under the temperatures and for the times necessary to nitride highly stressed components. Specifically, the use of heat-treatable steels soon comes up against limits when – and this is a correct procedure in materials engineering – a solution using steels more stable under tempering must be found.

Yet there are always fresh examples where the conversion from case hardening to nitriding has been successful for components susceptible to distortion. Two typical cases from the range of heat treatment parts at Härtereie Reese Weimar are rings of 42CrMo4V and measuring spindles of 16MnCr5, whose reject rates owing to changes in dimensions and shape during hardening or carbonitriding could not be justified. Converting to a gas nitriding treatment was able to lower considerably the reject rate without detriment to the demanded service values. Despite the classification of nitriding as a

**Figure 3.** Fatigue strength of gearwheels as a function of flank hardness (DIN 3990)



low-distortion hardening method with minimum dimensional changes, a successful solution was possible for both of these parts only after the manufacturing dimensions had been determined precisely on the pilot parts before nitriding, and the solution was of decisive importance for the successful implementation in major production plant.

**Figure 4** presents a summary of the results obtained from pilot investigations on rings with different ratios of outer to inner diameter. Nitriding took place at 510 °C over 36 hours. The CL thickness was 22 µm, and the ND 0.72 mm. It is interesting to note that the changes to the outer diameter are always in the positive area, whereas those to the inner diameter can be both positive and negative. Zero overall change was obtained with a diameter ratio  $D_o / D_i$  of about two. Fixing the pre-corrective dimensions for the ring's outer and inner diameters to values derived from this  $D_o / D_i$  ratio helped to retain the fit tolerance h8 for the inner diameter of over 90% of the rings in series production.

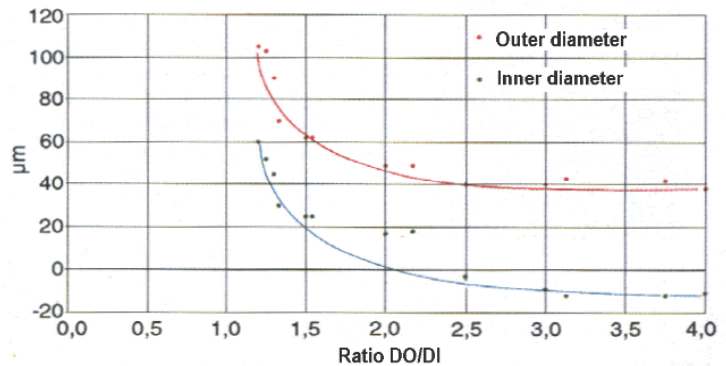
The conversion from case hardening to gas nitriding could be concluded with positive results for measuring spindles as well. For an l/d ratio of 62.5, concentricity after the nitriding treatment was less than 0.2 mm. A pre-correction to the length of -0.05% helped to retain the pitch accuracy within the permitted tolerance range for finish machining. Deviations still occurring sporadically in the lengths of series-produced parts exhibiting extremely high slenderness ratios led us to assume the effects of a plastic deformation caused by the compensation of compressive stresses in the surface layer together with the resulting predominance of tensile stresses acting in the lower part of the nitrided case. One other possible optimisation would be to use a steel exhibiting a higher yield strength as the spindle material. **Figure 5** shows a section of the measuring spindle with the dimensions 525 x 8 mm.

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[1] Edenhofer, B.: Härtereitechn. Mitt. 56 (2001) 1, p 14/22

[2] Liebmann, G.: Antriebstechnik 1996/9, p 12/16

**Figure 4.** Relationship between the ratio  $D_o/D_i$  and the changes in diameters of rings after gas nitriding



**Figure 5.** Gas-carbonitrided measuring spindles of 16MnCr5 steel

