Low Pressure Carburizing of Large Transmission Parts

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Management Summary

Often, the required hardness qualities of parts manufactured from steel can only be obtained through suitable heat treatment. In transmission manufacturing, the case hardening process is commonly used to produce parts with a hard and wear-resistant surface and an adequate toughness in the core. A tremendous potential for rationalization, which is only partially used, becomes available if the treatment time of the case hardening process is reduced. Low pressure carburizing (LPC) offers a reduction of treatment time in comparison to conventional gas carburizing because of the high carbon mass flow inherent to the process (Ref. 1).

By increasing the carburizing temperature, a further significant increase in productivity is obtained, which is not possible in gas carburizing systems to this extent due to furnace component and process limitations (Ref. 2). By adding micro-alloy elements such as aluminium, niobium and titanium as well as properly adjusting the nitrogen content, modern case hardening steels have become sufficiently fine-grain resistant even in temperatures above 1,000°C (1,830°F) (Ref. 3). Today's vacuum carburizing systems are suited for heat treatment in temperatures above 1,000°C.

Introduction

The combination of fine core resistant case hardening steels and suitable high temperature vacuum processes will lead to increased productivity especially in the large transmission industry, i.e., wind energy. Therefore, low pressure carburizing in combination with high pressure gas quenching (HPGQ) as applied in a vertical vacuum furnace platform offers the potential for heat treating large transmission parts.

Conventional Case Hardening of Large Gears

LPC and HPGQ processes are becoming more established in the case hardening of transmissions for automobiles and commercial vehicles. Until now, however, these processes were irrelevant in the treatment of large transmissions due to the lack of suitable furnace concepts for this process technology for large transmission parts with diameters of 600 mm (24") and more.

Therefore, large transmission parts are generally gas carburized in atmosphere pit furnaces and subsequently hardened in separate oil or polymer quench baths via open air transfer (Fig. 1). Direct hardening, being the most economic case hardening process, is generally performed on smaller

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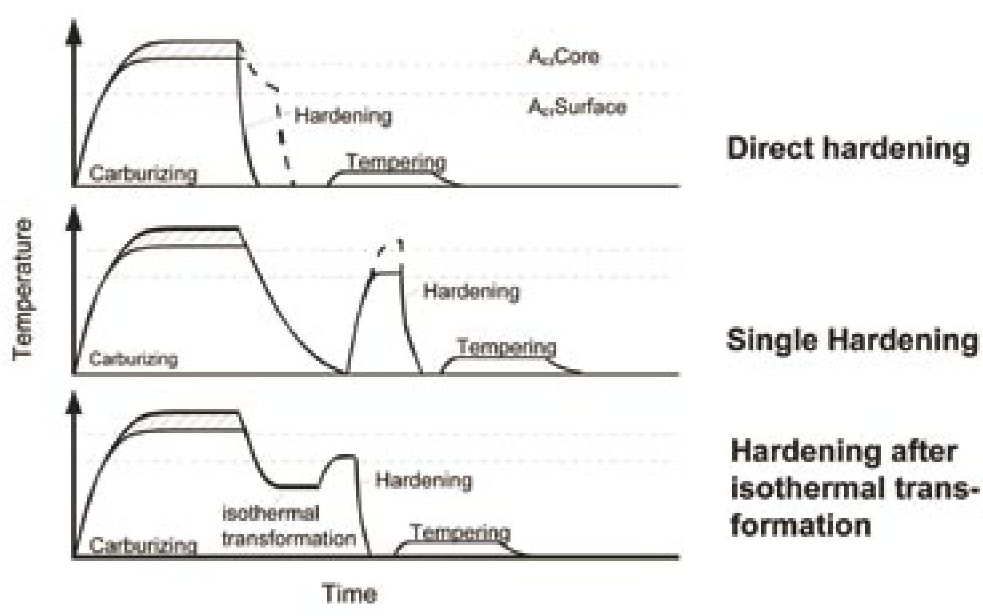

Figure 1—Atmospheric case hardening methods for large transmission gears.

gear wheels, i.e., the parts are quenched directly from carburizing temperature or after lowering to hardening temperature. Compared with single quench hardening, treatment time can be reduced by up to 20%. The reduced distortion allows for relatively small allowances for grinding, resulting in reduced production costs and improving gear tooth quality. Disadvantages include a slightly coarse structure and a higher residual austenite content. For larger gears, generally direct hardening after isothermal transformation or single hardening is performed, resulting not only in a significantly finer grain structure, but also in increased distortion. Due to long-term exposure in the specific atmospheric conditions during gas carburizing, the parts show a significantly higher amount of intergranular oxidation (IGO), which might lead to a soft surface layer and/or reduced fatigue properties during later service.

For hardening, the charge carriers loaded with transmission parts are removed manually from the pit furnace and submerged into liquid quench baths via air. This hot transfer may lead to increased part distortion as a result of warpage of change carriers through repeated use. Additionally, heavy smoke, unshielded flames and the immense thermal interference with the entire furnace surroundings carry a high risk potential to the operator of the facility.

LPC/HPGQ Processes for Large Gears

Low-pressure carburizing. While case hardening depths of 0.4–1.5 mm (0.016– 0.06") are common for automobile transmission parts, values ranging from 2 to 5 mm (0.08–0.2"), depending on the gear module, are standard for large transmission parts. This leads to a treatment time of many hours up to several days. Therefore, for economic reasons, the advantages of LPC should also be used for large transmission parts, preferably at high carburizing temperatures of up to 1,050°C (1,920°F). Suitable fine grain resistant steels are available in the market, thus eliminating the possibility of coarse grain formation, which might lead to uneven distortion, poor static and dynamic mechanical properties and

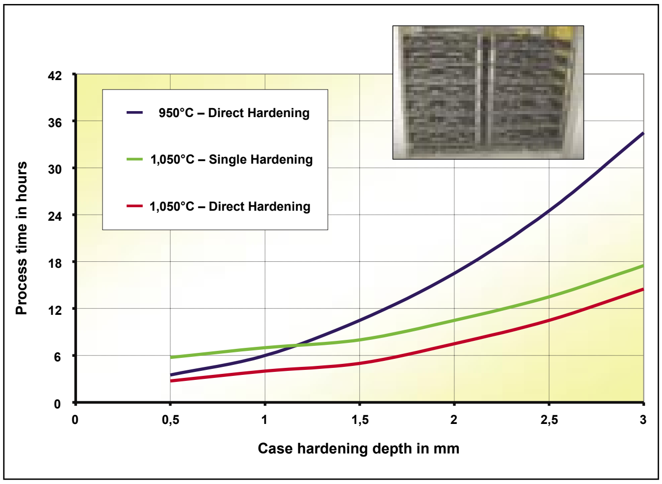

Figure 2—Process time depending on case hardening depth for different case hardening processes and temperatures (Ref. 5).

reduced toughness. For example, significant savings in process time can be achieved in the case hardening of large steel chains (Ref. 5) by increasing the carburizing temperature as shown in Figure 2. In case of standard low pressure carburizing that is directly hardened after carburizing at 950°C (1,740°F), a process time including heating and carburizing of 35 hours is necessary to achieve 3 mm (0.12") case depth. A drastic reduction in process time can be obtained by increasing the carburizing temperature to 1,050°C (1,920°F). Although the load needs to be reheated after carburizing for grain refinement to a temperature of 870°C (1,600°C) for three hours, the total process time could be reduced to 18 hours. Further time savings are possible with fine grain resistant case hardening steels allowing for direct hardening from 1,050°C (1,920°F). Slow cooling, reheating and oil or polymer quenching in a controlled atmosphere or vacuum furnace might be an alternative choice to LPC.

High-pressure gas quenching. HPGQ in combination with LPC is now commonly used to harden new transmission gears in the automotive industry. The steady increase of quench pressure and gas velocity and the continuous development of the processing technology allow increasing the quench intensity in such a way that even low-alloy case hardening steels can be successfully hardened (Ref. 4).

Compared with liquid quenching, "dry" quenching possesses many important ecological and economical advantages. The quench gases used, such as nitrogen and helium, are inert and leave no residue on the workload; therefore, an investment in washing machines and fire protection systems is not required. The use of gas recovery systems reduces gas consumption and lowers the operating costs in heat treatment. The most important difference to liquid quenching is the absence of phase transformations during quenching with gas, which secures a homogeneous heat transfer. A further advantage is the possibility to adjust the quench intensity by changing the gas pressure and the gas velocity to meet respective requirements, thereby creating the basic conditions to minimize quench distortion during quenching.

Quenching also plays an important role in obtaining the required strength properties. As mentioned earlier, automotive transmission parts made of low-alloyed case hardening steels are being successfully quenched using a specially-developed gas quench technology. In the field of large transmissions, however, higher quench intensity is required because of the parts' larger cross sections. Since a further increase in quenching intensity of the current gas quench technology would exceed technological and economical limits, the use of this technology for large transmission parts only makes sense if case hardening steels with a high hardenability are used.

Today, a number of case hardening steels—23MnCrMo5, SAE 9310, SAE 4320 or Ovako 277—are available which are well suited for gas quenching of large parts because hardenability-enhancing elements such as nickel, chrome, molybdenum and manganese are added. Further to the addition of alloying elements, the suitable pre-treatment of material during steel production also enhances hardenability. Following the change in pre-treatment from "FP (ferrite/pearlite-annealed)" to "quenched and tempered," considerably higher core hardness values were obtained in samples consisting of material 18CrNiMo7-6 when subsequent case hardening and gas quenching were performed.

Furnace Technology for LPC of Large Gears

In addition to a suitable carburizing and quench technology, the case hardening of large transmission parts requires a suitable furnace technology. Vacuum pit furnaces with integrated gas quenching are especially suited. For many decades, these plants have been successfully used to vacuum harden, anneal and braze large parts, particularly in the aviation and tooling industries. The furnaces' working space dimensions range from 600 to 2,000 mm (24" to 80") in diameter and are up to 2,000 mm (80") high. Charging is either from the bottom by means of a lowerable charge table or from the top via crane, depending on the design. The heating chamber is insulated with graphite board and electrically heated with graphite rods to a maximum temperature of about 1,250°C (2,300°F). This type of insulation possesses a relatively low thermal mass and is therefore rapidly heated. The excellent insulation properties guarantee a low thermal loss and high temperature uniformity. This heating chamber design delivers optimum performance as proven in the low pressure carburization of automobile transmissions.

The furnaces are equipped with an integrated gas quench system, consisting of a gas fan, a heat exchanger as well as the appropriate gas guiding systems. For high-alloyed materials used in the aviation industry, a quench pressure of 2 bar is generally adequate. The tool industry, however, uses quenching at pressures up to 20 bar. The integrated gas quench system does not have the quenching intensity of a separate cold quench chamber. However, it does eliminate the transport of hot parts, which are very prone to distortion. Depending on the application, various quench methods can be realized. Figure 3 shows a typical pit furnace with a bottom loading design used for heat treating of tools. Gas quenching is performed by vertical gas flow from top to bottom or bottom to top. To achieve a uniform quench throughout the load, the gas flow can be reversed during the quench. As another example, Figure 4 shows a pit furnace concept that can be loaded from the top. Quenching in this furnace is done by using vertical graphite tubes arranged in a circle in the heating chamber. The tubes feature several radial nozzles where the quench gas is dispersed uniformly to the parts. Additionally the system is equipped with a rotating charge table, which evens hardening scatter band, thereby reducing quenching distortion.

The combination of high temperature vacuum carburizing and high pressure gas quenching in connection with suitable vacuum pit furnaces opens up new perspectives for economic and low-distortion case hardening of large transmissions,

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Figure 3—Bottom loader for LPC of large parts with integral gas quench.

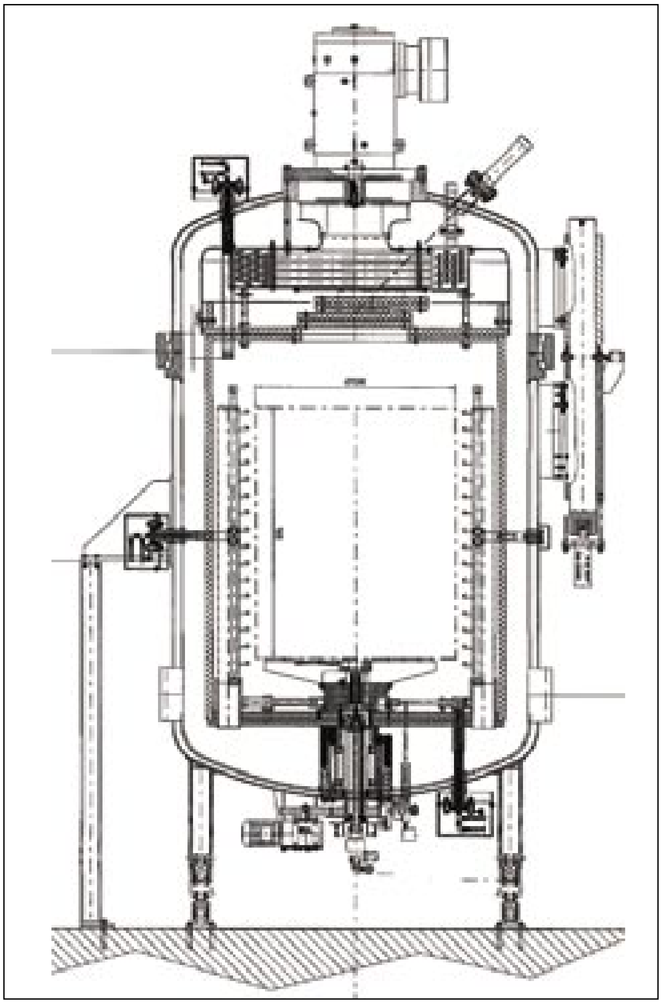

Figure 4—Top loader concept with integrated nozzle cooling for LPC of large transmissions.

made possible by the parallel development of fine grain resistant and high hardenability case hardening steels (Fig. 5). As in conventional case hardening processes, it is possible to perform direct hardening with or without isothermal transformation as well as single hardening. If it is not possible to successfully gas quench the material, the parts may be rapidly carburized in the vacuum furnace, cooled in gas and subsequently quenched in the conventional pit furnace using an oil quench. This technology features a number of other advantages such as uniform and rapid carburizing without IGO as well as homogeneous, low-distortion quenching.

The energy consumption is low because the furnace employed is only heated during the process. Heating and gas absorption during idle phases are not necessary. The process gas consumption is minimal because of the pulsed carburizing technology with acetylene in vacuum. Figure 6 shows the carbon profile of 18CrNiMo7-6 material after carburizing at 1,050°C (1,920°F) to a case depth of 2.5 mm (0.1"), as calculated with the simulation software *VC-Sim*. To carburize large gear components with a total surface of 15 m^2 (160 ft^2) to that case depth, a net carburizing time of only 8 minutes and an acetylene volume of only 2.25 m^3 (80 ft^3) are necessary.

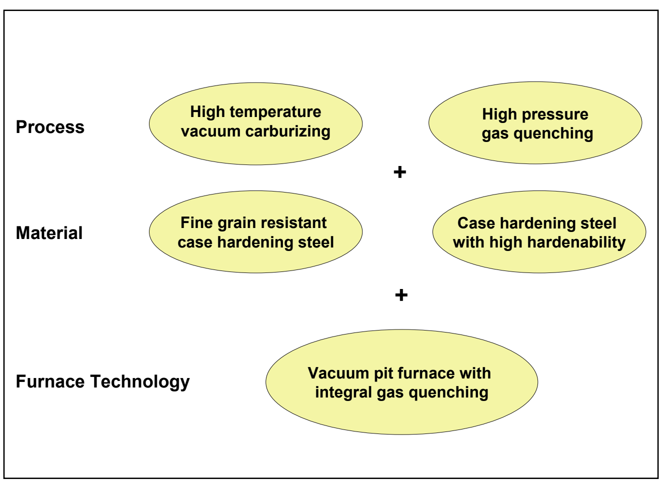

Figure 5—New technology for case hardening of large transmission gears.

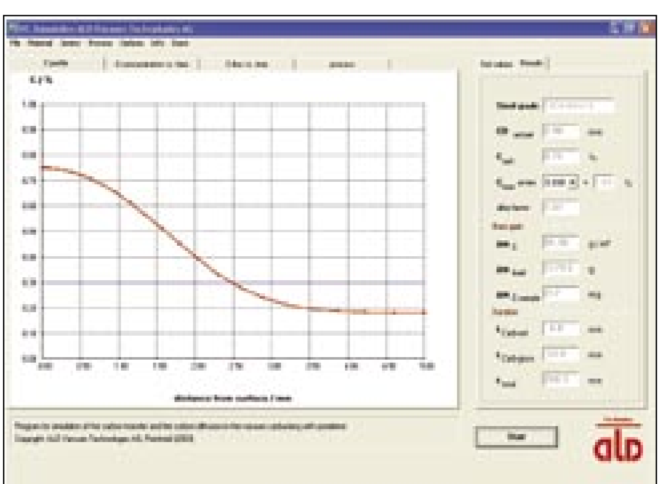

Figure 6—Calculated carbon profile after LPC at 1,050°C (*VC-Sim* software).

The furnaces show only slight thermal and gaseous emissions and are fully automated. Following the quench process, the parts are dry, clean and bright. The minimized distortion enables significant reduction in subsequent grinding processes, which leads to reduced hard machining costs and case depths.

Conclusion

Case hardening using vacuum carburizing and subsequent high pressure gas quenching has become widely established in the heat treatment of automobile parts in the recent years. However, the advantages of this technology are not limited to small transmission parts and low case hardening depths. The combination of high temperature vacuum carburizing and high pressure gas quenching in connection with suitable vacuum pit furnaces and suitable case hardening steels will hopefully open up new perspectives for the economic and low-distortion case hardening of large transmissions found in wind energy transmission components.

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