A Member of The Linde Group

Carburising and Carbonitriding

Carburising and carbonitriding are often referred to as case hardening. This is because this is exactly what the do – form a hard case or shell around the still tough core of a steel component.

Why case harden?

It's mainly to do with wear. In general terms the harder a piece of steel is the less it wears. So if we are producing a component like a gear we want it to be as hard as possible so that it does not wear out. Unfortunately, in steels, high hardness has other consequences – one of those is loss of ductility. Hard steel tends to be brittle. So, if we made our gear out of hard, wear resistant steel, then as soon as it was shocked – by changing gear for instance – the gear teeth would fracture and fall off. The solution to the problem is case hardening - a hard wear resisting outside and a tough shock resisting core.

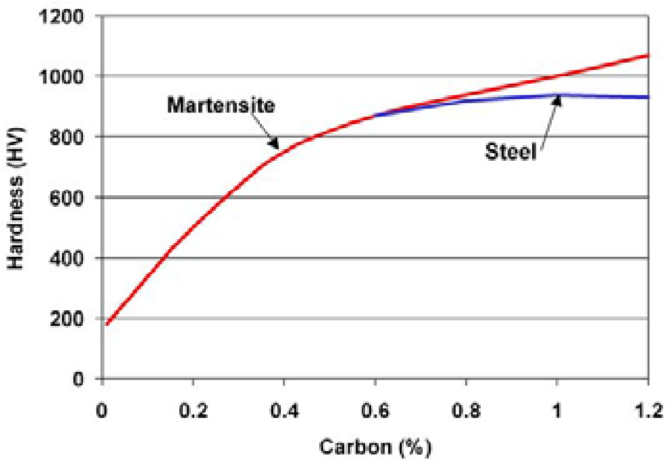

Figure 1. The dependency of hardness on carbon content of steel

How is it done?

Fortunately for the automotive industry, the biggest user of gears, the hardness of quenched steel is related to its carbon content as illustrated in Figure 1. So, if we start with a tough, low-carbon steel and add carbon to the surface we will end up with the sort of duplex structure we are after.

Back in the dark ages before computers, the carbon was added to the surface by heating up the gear to around 900°C for a few hours packed in charcoal. Carbon was transferred from the charcoal to the steel and diffused in to form a case when the gear was quenched. All fairly crude, but it got you there.

Important things about the case

If there is too little carbon in the case, it will be softer than it could be and will wear more quickly. If it is too high there can be two distinctly different results. If it is just a bit too high, then instead of the nice hard martensite, we start to "retain" some of the high temperature phase called austenite which is soft. As a result the case gets softer (Figure1). This problem can be corrected by cooling the gear below room temperature increasing the hardness as shown by the second line in Figure 1. This can be achieved using a Linde CRYOFLEX® cryogenic treatment chamber.

If the carbon level increases even further we reach the limit of solubility of carbon in steel and start to form a very hard, very brittle compound, iron carbide, in the steel. This is not too bad if the carbide is in the form of small balls as it improves some types of wear. However, it usually forms as a network at the surface and this leads to cracking. It can be converted to the ball type by re-heating and quenching from around 850°C. This is what the old timers did routinely with the charcoal treated parts, slow cool from the furnace to ball up the carbide, then re-heat and quench.

The hardness distribution and total depth of the case is also important. An idealised hardness profile is shown in Figure 2. The high hardness plateau represents the depth of wear beyond which the part is unserviceable. More case than this is a waste of time and money. The transition from case to core is important. Too steep and stresses will be produced at the interface leading to spalling of the case in service. Too shallow and not only a waste of time but a reduction in toughness of what should be core. If the total case is too deep there will be insufficient tough core to withstand impact loading. The control necessary to reach this result can be achieved using a CRYOFLEX® carbon control system.

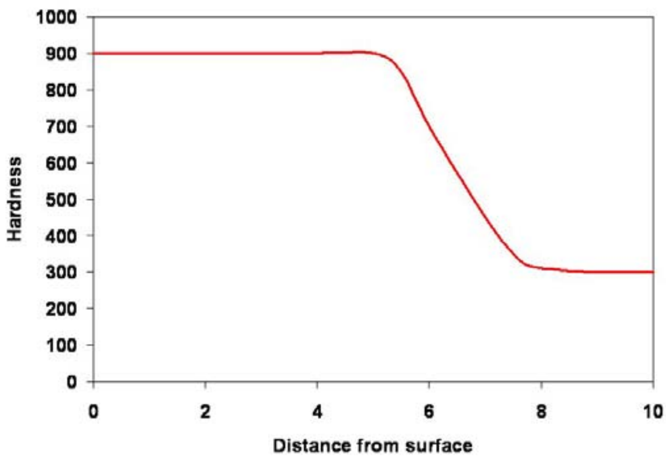

Figure 2. Idealised case hardness profile

Case hardening mild steel

Most case hardened components are made from low alloy steel so they are hard enough when quenching in oil. To lower costs some components are manufactured from mild steel. Mild steel needs a faster water quench achieve a hard carburised case and in larger sections even that is not enough. The answer is to add some nitrogen to the case in a process called carbonitriding. This decreases the quenching rate needed to harden the steel. Our old timers would include some leather clippings and bones with their charcoal to add the nitrogen.

Modern case hardening technology

Because pack carburising in charcoal is so uncontrollable, not to say messy, a cleaner alternative was sought. Unfortunately, most easily available hydrocarbons do not transfer their carbon to steel well at carburising temperatures. A transfer agent is needed. Carbon monoxide performs this role well, but needs hydrogen to release the carbon dioxide formed from the steel surface as shown in Figure 3. The required gas mixture is generated from natural gas or propane by an endothermic reaction and contains approximately 20% carbon dioxide, 40% hydrogen and 40% nitrogen. This can also be achieved using the heat from the furnace in a CARBOCAT® insitu atmosphere generator. Later the same mixture was produces from thermally cracked methanol and nitrogen. Linde's CARBOTHAN® atmospheres are an example of this. If carbonitriding is needed ammonia is added as the source of nitrogen as nitrogen itself is effectively inert at these temperatures.

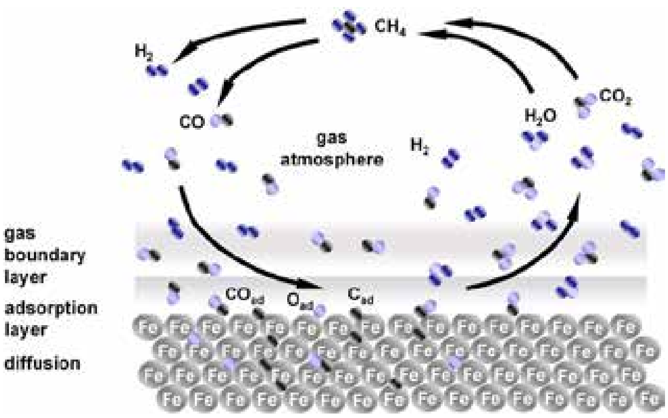

Figure 3. The carburising mechanism in endothermically generated gas

These gas carburising technologies dominate the market today with the sealed or integral quench furnace, shown diagrammatically in Figure 4, being the workhorse of the industry. The parts, usually jigged to keep the apart, enter the vestibule through the front door. Once purged with endothermically generated carburising gas, the middle door opens and they are transferred to the hot chamber for carburising and the middle door is closed. After the time required to achieve the desired case depth the load is transferred back to the vestibule and is lowered into the oil bath to quench it. Once cooled it exits back through the front door. During the carburising phase the carbon level in the steel is controlled by the amount of hydrocarbon added to the endothermically generated gas mixture.

Even though this process works well it is now viewed as insufficiently environmentally friendly. Heat and flames from the burning atmosphere gases as they leave the furnace make it difficult to integrate into modern manufacturing cells and the parts need to be washed after treatment to remove the quench oil before they can be processed further. After several false starts, we now have low pressure carburising using acetylene as the carbon source followed by high pressure gas quenching usually with nitrogen or helium if a faster quench is needed. As the process takes place entirely in a sealed, cold-wall vacuum furnace it can be integrated into production lines (Figure 5) and parts emerge clean and dry ready for the next operation.

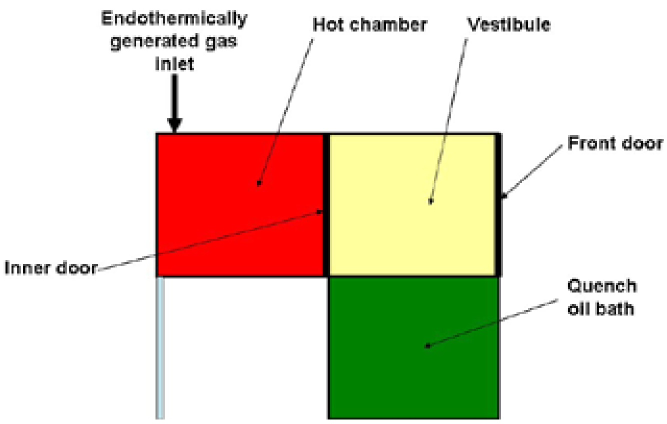

Figure 4. Schematic of a sealed quench furnace

Figure 5. A modular vacuum carburising system at BMW (photo courtesy of ALD)

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