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Hardening, tempering and austempering

Hardening, tempering and austempering are processes whereby steel is made stronger and more wear resistant.

Why harden, temper or austemper?

In general terms, parts are manufactured from steels that are in their softest possible condition. This makes cutting, bending, stamping etc. as easy as possible. However, in the final application, the part may need to be hard, wear resistant, tough or strong or some combination of these. It is the hardening, tempering and austempering processes that transform the part from one to the other.

How is it done?

At room temperature soft steel is a mixture of iron and iron carbide. When it is heated above 720°C the iron carbide begins to dissolve in the iron to form a solid solution called austenite. If this were slow cooled again, it would go back to iron and iron carbide. However, if it is quenched there is insufficient time for this to happen. The carbon becomes trapped in the austenite as it tries to get to the low temperature structure forming what is known as martensite. Because of the trapped carbon, the martensite is hard, the more carbon in the steel the harder and stronger the martensite, but the more brittle it becomes.

After quenching the steel is termed fully hardened. This condition is unsuitable for most applications because it is too brittle, so it is tempered. In tempering the steel is heated to a temperature usually in the range 150 to 450°C. This provides some energy to allow some of the trapped carbon atoms to pop out, so relieving the stress. The higher the temperature the more the stress is relieved and the softer, but tougher the steel becomes.

Austempering is a sort of short cut. Instead of quenching down to room temperature the parts are quenched into a molten salt bath at between about 230 and 330°C. The steel transforms to a material called bainite which is very like tempered martensite, but even tougher.

Tool steels

Tool steels are generally highly proportion of alloying elements. In the soft condition these are tied up as carbides. The tool steel has to be heated to a very high temperature to get these alloy carbides to dissolve and even then not all do. When the tool steel is cooled it is very hard indeed. As tempering temperature increases, like the ordinary steel the hardness falls. However, as the temperature rises further it begins to increase again (Figure 1). This is because fine alloy carbides are being reformed from solution. This is called secondary hardening and occurs at around 550°C. The result is a very tough wear resistant material.

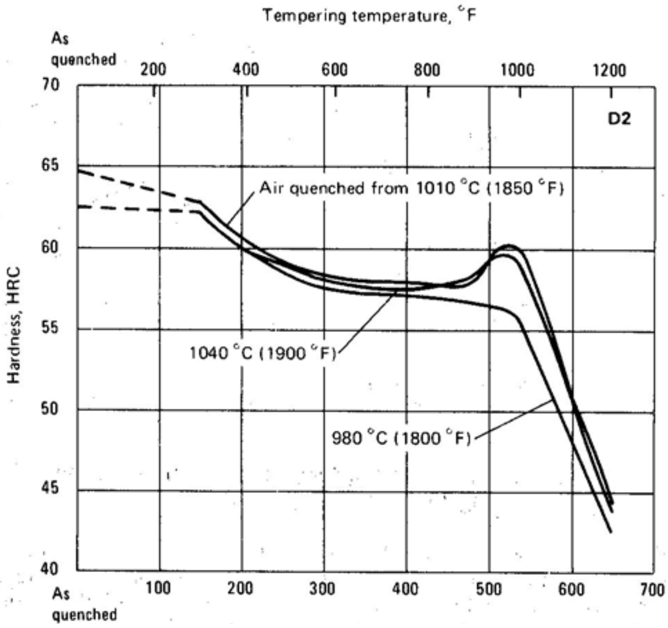

Figure 1. Tempering of D2 tool steel

Quenchants

The severity of the quench needed to transform a given steel to martensite varies with composition. As a general rule the higher the alloying elements the slower the quench can be. For a highly alloyed tool steel just cooling in air (or argon if the surface needs to be protected) is good enough. For moderate to low alloy steels oil or high pressure gas quenching is needed. For steels with virtually no alloying elements water is needed. However, if the rate is too high cracking will probably result.

Section size

The other factor that affects the quenching rate needed is the section size. The thicker the part the faster the quench needs to be to fully harden it. If we take gas quenching as an example where quenching rate increases with gas pressure then a steel that needs 10 bar nitrogen at 20 mm diameter may need 20 bar at 30 mm. Parts with widely differing sections can be difficult to process as the quench necessary to harden the larger section might crack a smaller one.

What types of furnace are used?

Furnaces used for hardening must have some form of associated quench facility. Some, like the pit furnace shown in Figure 2, have a separate facility. The parts must be removed from the heating furnace and transferred to the quench. As the transfer is in air, some oxidation occurs. Other examples of this type of furnace are rotary heath furnaces and rotary barrel furnaces. They all have the advantage that any type of quenchant can be used.

If oxidation is to be avoided the heating up and the transfer to the quench medium must be done in a protective atmosphere. Examples of this type of furnace are sealed or integral quench furnaces (Figure 3) and shaker hearth furnaces. As the atmosphere in the quenching zone and the heating zone interact the quenchant is normally restricted to oil.

Figure 2. Parts being withdrawn from a pit furnace for quenching

Figure 3. Sealed quench furnaces

Another example of the protected quench furnace is the single-ended mesh belt furnace. In this type of furnace the parts are conveyed through the furnace on a wire mesh belt which returns in a continuous loop under the hearth. When the parts reach the end they fall off and down a chute into the quenchant. Usually the quenchant is oil, but this type of furnace is also used for austempering where the quenchant is molten salt. An example of this type is shown in Figure 4.

Tools are typically hardened in a vacuum furnace because of the high temperatures needed. An example is shown in Figure 5. The quenchant is typically low pressure argon as the cooling rates needed are not high and temperatures are high enough to get nitriding if nitrogen ere used.

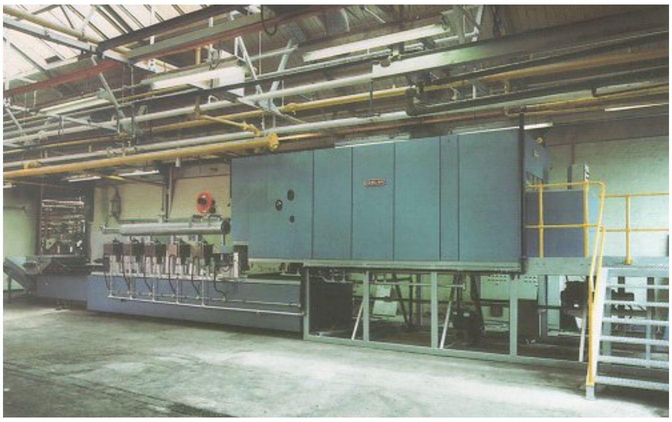

Figure 4. A mesh belt furnace used for austempering

Figure 5. A vacuum furnace used for hardening tools

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