HARDENING AND TEMPERING OF ENGINEERING STEELS

(A separate CHTA datasheet relates to "Hardening and Tempering of Tool and Die Steels")

WHAT ARE THE TREATMENTS?

Hardening and tempering of engineering steels is performed to provide components with mechanical properties suitable for their intended service. Steels are heated to their appropriate hardening temperature (usually between 800-900°C), held at temperature, then "quenched" (rapidly cooled), often in oil or water. This is followed by tempering (a soak at a lower temperature) which develops the final mechanical properties and relieves stresses. The actual conditions used for all three steps are determined by steel composition, component size and the properties required.
Hardening and tempering can be carried out in "open" furnaces (in air or combustion products), or in a protective environment (gaseous atmosphere, molten salt or vacuum) if a surface free from scale and decarburisation (carbon loss) is required ("neutral hardening", also referred to as "clean hardening").
Two specialised quenching options can be applied in special circumstances:

Martempering (also known as "marquenching") uses an elevated-temperature quench (in molten salt or hot oil) which can substantially reduce component distortion. This process is limited to selected alloy-containing steels and suitable section sizes.

Austempering can be applied to thin sections of certain medium- or high-carbon steels or to alloy-containing steels of thicker section. It requires a high-temperature quench and hold, usually in molten salt, and results in low distortion combined with a tough structure that requires no tempering. It is widely used for small springs and pressings.

WHAT ARE THE BENEFITS?

Hardening and tempering develops the optimum combination of hardness, strength and toughness in an engineering steel and offers the component designer a route to savings in weight and material. Components can be machined or formed in a soft state and then hardened and tempered to a high level of mechanical properties.
Hardening from open furnaces is often employed for products such as bars and forgings that are to be fully machined into components afterwards. Neutral / clean hardening is applied to components that require surface integrity to be maintained; examples include nuts, bolts, springs, bearings and many automotive parts. Neutral / clean hardening is carried out under tightly-controlled conditions to produce a precision component needing the minimum of final finishing.

WHAT SORT OF STEELS CAN BE TREATED?

Almost all engineering steels containing over 0.3% carbon will respond to hardening and tempering. BS970 and BS EN 10083-1 and -2 (which have superseded parts of BS 970) list the majority of hardenable steels used for engineering components. (A number of other standards include hardenable steels for special applications; e.g. "S" aircraft standards, BS3111 for fasteners and BS5770 for springs)

Consult your heat treater when selecting steels for hardening treatments.

WHAT ARE THE LIMITATIONS?

Hardening response

The response of a steel component to hardening and tempering depends on steel composition, component size, and method of treatment. Guidance is given in BS970 and BS EN 10083-1 and -2 on the mechanical properties obtainable in steels with different section sizes using recommended treatment parameters. Use these as a guide to steel selection.
Every steel has a "limiting" section size ("ruling section") above which full hardening cannot be achieved. A higher grade of steel will be required to ensure optimum properties in a larger section.
It may be possible to harden larger components in lower-grade steels by using non-standard treatments such as faster quench rates or lower-temperature tempers. Faster quench rates *always* increase the risk of distortion or cracking, and low-temperature tempers can seriously impair mechanical properties such as toughness. Serious consideration should be given to these facts before asking for non-standard treatments to be carried out.

The negative effect of aluminium

Plain-carbon non-alloy steels, and some low-alloy steels, can contain excessive amounts of aluminium which can have a harmful effect on hardening response (lower than expected hardness). The CHTA datasheet "Anticipating the Hardening Response of Aluminium-bearing Plain-carbon Steels" gives guidance on avoiding this serious problem. It is important to ensure that aluminium and nitrogen contents are listed on the mill certificate from the steel supplier.

Steel condition
Steels that are purchased after open treatments (e.g. 'black bar') are liable to have lost some carbon from the surface layers (decarburisation). Decarburised layers *must* be fully removed by machining from all surfaces before components are hardened, otherwise excessive distortion or even cracking are likely.
Steels that are purchased in cold-worked conditions, such as 'bright bar', contain residual stresses. These stresses can contribute to distortion during machining and in hardening. It is recommended that rough-machined blanks have these stresses removed, by normalising or soft annealing before hardening, in order to reduce the risk of excessive distortion.

Temper embrittlement
Certain steels, particularly alloy steels containing nickel and chromium, suffer from embrittlement if tempered in the range 250-450°C; this limits the acceptable mechanical properties they can attain. Check that the selected steel is not prone to this problem, and if in doubt consult your heat treater.

Component size and shape
The size and shape of a component that can be hardened and tempered depends on the type of equipment operated by the heat treater. Overall, items that can be handled within the contract heat treatment sector range from those of a few grams to components weighing several tonnes each. For large components, check the availability of suitably-sized facilities at an early stage.

WHAT PROBLEMS COULD ARISE?

Distortion or cracking
Changes in size or shape can arise in hardened components from a variety of causes, some inherent in the high-temperature / rapid-cool process, some attributable to component design shortcomings and others relating to earlier manufacturing steps (e.g. thermal relief of stresses introduced by prior forming).
Where final dimensions are critical, finish grinding or machining will be necessary and must be planned. Components hardened and tempered to high mechanical-property levels are often impossible to straighten later.
In extreme circumstances, the stresses generated by quenching can even be high enough to crack components. It is necessary for the manufacturer to take all reasonable steps to minimise the risk through careful component design (e.g. avoid stress-raising features such as sudden changes in section, deep slots, cutouts) and steel selection.
It is always helpful to consider potential hardening and tempering problems at the design stage.

Scaling and decarburisation
If open furnace treatment is selected, scaling and decarburisation are likely. Large components spend longer at high temperatures and suffer more. Allowance must be made for removal of affected layers after treatment. The alternative is clean/neutral hardening in a protective environment which avoids scaling and decarburisation.

Mixed batches
Components made from mixed batches ("casts") of material pose problems to your heat treater. He cannot separate components supplied in one load made from steels having the same material specification but different compositions. Components made from steels with varying compositions can respond differently to the hardening treatment, resulting in rejections, rework and added cost to all parties. Assist your heat treater by keeping material batches separate.

HOW DO I SPECIFY?

All of the following information should be included if possible. *If uncertain, ask your heat treater before producing a specification:*

- **Treatment required**: this could be harden and temper, martemper or austemper. Indicate if neutral / clean treatment is essential or if open treatment is satisfactory.
- **The steel specification:** including the steel designation and the standard from which it is drawn, plus actual composition as given on the mill certificate from the supplier.
- **Mechanical properties required**: generally a hardness range or tensile strength range can be quoted from the standard being worked to. It is not possible to attain a specific figure due to variables outside the heat treater's control; allow a realistic working range.
- **Testing required**: indicate the type(s) of testing required (e.g. Vickers, Rockwell or Brinell hardness) and any special locations for testing or the removal of samples for test pieces.
- **Certification**: are there requirements for any special certificates or data to be provided by your heat treater?
- **Drawings/standards**: provide details of any drawings or standards, especially company or in-house standards, that contain relevant details which must be adhered to.
- **Other requirements**: indicate if other services are required, e.g. straightening, (with working limits), cleaning/blasting, laboratory or specialised non-destructive tests, etc.

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