training of operators in manual 'burn-out' procedures is extremely important in the event of failure of automatic controls. These emergency instructions may vary with equipment design, and thus the importance of consulting and understanding emergency procedures, as outlined by the furnace manufacturer's instructions, should not be minimised.

Protective Controls

Protective devices should be installed and interlocked and should include the following:

- 1. A safety shut-off valve on the atmosphere supply line to the furnace.
- 2. An atmosphere gas-supply monitoring device that permits the operator to visually determine the adequacy of atmosphere gas flow at all times.
- 3. A sufficient number of temperature-monitoring devices to determine temperature in all zones of the furnace; these should be interlocked to prevent opening of the atmosphere-gas-supply safety shut-off valve until all zones are at or above 760°C (1400°F).
- 4. An automatic safety shut-off valve for flame curtain burner supply gas; this should be interlocked to prevent opening of the valve when furnace temperature is below 760°C (1400°F).
- 5. Audible and/or visual alarms to alert the furnace operator of abnormal conditions
- 6. Manual door-opening facilities to permit operator control in the event of power failure.

Operator Training

The most essential safety consideration is the selection of alert and competent operators. Their knowledge and training are vital to continued safe operation. New operators should be instructed thoroughly and required to demonstrate an adequate understanding of the equipment and its operations.

Regular operators should receive scheduled retraining to maintain a high level of proficiency and effectiveness, and all operators should have ready access to operating instructions at all times. An outline of these instructions should be posted near the furnace.

Operating instructions generally are provided by the equipment manufacturer, and these instructions include schematic piping and wiring diagrams. All such instructions should include procedures for light-up, shut-down, emergencies and maintenance.

Operator training should include instructions in:

- 1. Combustion of air-gas mixtures
- 2. Explosion hazards
- 3. Sources of ignition and ignition temperature
- 4. Atmosphere gas analysis
- 5. Handling of flammable atmosphere gases
- 6. Handling of toxic atmosphere gases
- 7. Functions of control and safety devices
- 8. Purpose and basic principles of atmosphere-gas generators.

This listing is intended only to serve as a guideline.

PROCESS COOLING

Heat treating of metals includes controlled cooling or quenching of the heated metal; metals are cooled from the specific treatment temperature in a variety of media which include air, oils, salts, water and synthetic fluids.

Chapter 8

Low and High Temperature Thermomechanical Heat Treatment

INTRODUCTION

Plastic deformation can change the pattern of distribution and increase the density of imperfections, such as dislocations, vacancies, stacking faults, low- and high-angle boundaries in a crystal structure. Since crystal lattice defects produce a strong effect on the formation of structure in alloys during phase transformations, plastic deformation before or during phase transformations can be used to form the optimum structure in a heat-treated alloy.

Thermomechanical treatment is a kind of heat treatment including plastic deformation which increases the density of defects and thus affects the formation of the structure in the phase transformations occurring during the thermal action.

Consequently, not every combination of straining, heating and cooling can be called thermomechanical treatment. For example, if plastic deformation is carried out after all operations of heat treatment, we are dealing with common heat treatment followed with plastic working rather than with thermo-mechanical treatment. Such plastic deformation, for instance, cold rolling after ageing, may produce strain-hardening and increase strength properties but has no effect on the structure formed through phase transformations, since these transformations have taken place before the plastic deformation was applied.

If plastic deformation was effected prior to heat treatment and produced no decisive effect on the final structure formed in an alloy during phase transformations, it should be regarded as a simple combination of plastic deformation and heat treatment, rather than thermomechanical treatment. For example, cold rolling followed by heating for quenching, during which re-crystallisation takes place, are not components of thermomechanical treatment, since the re-crystallised structure has a low density of crystal imperfections.

The processes of plastic deformation and heat treatment in thermo-mechanical treatment may be either combined in a single technological operation (i.e., carried out simultaneously) or made with a time interval of up to a few days one after the other. It is only important that phase transformations take place under the conditions of increased density of the lattice defects formed through plastic deformation.

At present, various methods of thermomechanical treatment are being used or tested in the industry; all of them include plastic deformation which produces a decisive effect on the formation of the structure in alloys on ageing or during polymorphic, mainly martensitic, transformations.



Fig. 9.1 Schemes of high-temperature (HTHT) and low-temperature (LTHT) thermo-mechanical treatment of martensite-hardened alloy steel.

The cause why steels are strengthened on LTHT lies in that the martensite inherits the dislocation structure of the deformed austenite.

Cold deformation cannot produce a high strengthening in martensitic steel, since the martensite, which contains much carbon, is brittle and cannot be deformed with high reductions. On the contrary, austenite can be heavily deformed at temperatures below the point of beginning of re-crystallisation. Such a deformation can strongly increase the total density of dislocations in austenite, with the formation of dense dislocation tangles and a cellular structure.

With martensitic transformation, neighbours of any atom in the austenite remain such in the martensite. Therefore, dislocations do not disappear in the $\gamma \rightarrow \alpha$ -transformation by the martensitic mechanism, but are 'passed over' from the initial phase to the new one, i.e., the martensite inherits the sub-structure of deformed austenite. A very high density of dislocations in martensite, which are locked by carbon atoms and carbon precipitates, is responsible for the record figures of ultimate strength on LTHT of steels.

The large refinement of martensite crystals explains why the steel in the high-strength state can have an acceptable level of ductility indices.

LTHT is practically applicable only to alloy steels possessing an appreciable stability of undercooled austenite.

To obtain record figures of ultimate strength (up to 330 kgf/mm²), alloy steels can be subjected to LTHT by the scheme: austenitisation with heating above $Ac_3 \rightarrow$ undercooling of austenite down to 600-400°C \rightarrow plastic working with deformation up to 90 per cent \rightarrow martensite hardening \rightarrow tempering at 100-200°C.

The gain in strength properties on LTHT depends on the degree and temperature of straining, the temperature of tempering, the content of carbon, and other factors. The strengthening effect on LTHT increases continuously with increasing degree of deformation.

Fig. 9.2 shows how the temperature of rolling in LTHT can affect the properties of Cr-Ni-Mo steel. The rise in the strength properties of steel on lowering the temperature of deformation is caused by increased strain hardening of the austenite. The loss in strength properties on rolling at 400°C is due to bainitic transformation taking place during deformation. Since the non-martensitic products of the transformation which are formed in LTHT can lower the strength, the process must be carried out so as

suggests that this overheating is concerned in some way with a diffusion and precipitation process, involving MnS. Such overheating can occur in an atmosphere free from oxygen, thus emphasising the difference between overheating and burning.

As the steel approaches the solidus temperature, incipient fusion and oxidation take place at the grain boundaries. Such a steel is said to be burnt and it is characterised by the presence of brittle iron oxide films which render the steel unfit for service, except as scrap for re-melting.

Quench Cracks

The volume changes which occur when austenite is cooled are:

- 1. Expansion when gamma iron transforms to ferrite.
- 2. Contraction when cementite is precipitated.
- 3. Normal thermal contraction.

When a steel is quenched these volume changes occur very rapidly and unevenly throughout the specimen. The outside cools most quickly, and is mainly martensitic, in which contraction (2) has not occurred. The centre may be troostitic and contraction (2) started. Stresses are set up which may cause the metal either to distort or to crack if the ductility is insufficient for plastic flow to occur. Such cracks may occur some time after quenching or in the early stages of tempering.

Quench cracks are liable to occur:

- 1. Due to presence of non-metallic inclusion, cementite masses, etc.
- 2. When austenite is coarse grained due to high quenching temperature.
- 3. Owing to uneven quenching.
- 4. In pieces of irregular section and when sharp re-entrant angle are present in the design.

Relation of design to heat treatment

The relation of design to heat-treatment is very important. Articles of irregular section need special care. When a steel has been chosen which needs a water-quench, then the designer must use generous fillets in the corners and a uniform section should be aimed at. This can sometimes be obtained by boring out metal from bulky parts without materially affecting the design; examples are given in Fig. 9.5. A hole drilled from the side to meet a central hole may cause cracking and it should be drilled right through and temporarily stopped up with asbestos wool during heat-treatment. A crack would also form at the junction of the solid gear with the shaft and there would be a serious danger of cracks at the roots of the teeth owing to the great change in size of section. This design could be improved by machining the metal away under the rim to make a cross-section of uniform mass.

Low melting point compounds

Low melting-point compounds, such as iron sulphide in steel, nickel sulphide in nickel, are a common cause of cracked welds, especially in welding free-cutting steels. The addition of sufficient manganese largely overcomes the troubles in steel by forming a high melting-point sulphide.

Ranges of low ductility

Ranges of low ductility occur in some materials within certain temperature ranges as shown in Fig. 9.6. If welds are stressed at about 700°C cracks may develop.