Trade of Toolmaking

Module 5:	Press Tools, Jigs & Fixtures, Mouldmaking
Unit 4:	Introduction to Heat Treatment
	Phase 2

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Unit Objective

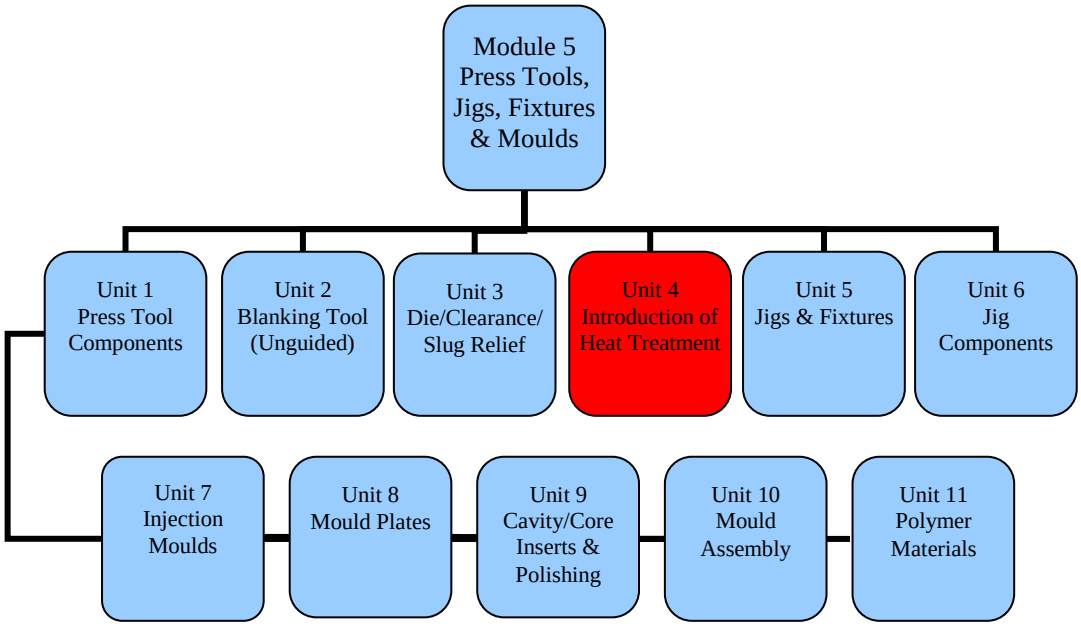
On completion of this unit you will be able to explain how steel is produced and describe the various types of heat treatments. You will also learn how to safely heat treat steel.

Introduction

Module five of this course covers Press Tools, Jigs & Fixtures, Mouldmaking. This is the forth unit in module five and explain how iron and steel is produced. Iron is most common metal used in the world and is used through out industry.

Steel is used for many applications in the workshop and Toolrooms to manufacture components used in press tools, moulds, jigs and fixtures. Depending on the application, different types of steels are available. For components used in fixtures or certain parts of a press tool where strength and toughness is required, mild steel is used. For components such as punches and dies used in press tools, the steel needs to be harder and have good wear properties. For these applications tool steel is available in softer annealed state so that it can be easily machined. The properties in the tool steel allow it to be heat treated in a furnace to produce a harder material.

Safety requirements must be adhered to when using a furnace to heat treat steel components.



By the end of this unit you will be able to:

- Identify from where steel originates and describe how steel/iron is produced.
- Describe the various types of heat treatments on steel.
- List and describe the properties of a range of non-ferrous metals.
- List the safety precautions to be adhered to when heat treating steel.
- Safely harden and temper components utilising heat treatment specifications charts.
- Identify the use and /or the alternatives to case hardened materials and surfaces.

1.0 The Origin Of Steel And Steel Production

Key Learning Points

Extraction of iron ore and production of iron and steel.

1.1 Extraction Of Iron Ore And Production Of Iron And Steel

Iron is an element that is extracted from iron ore, which is mined in various parts of the world. In order to produce steel, the iron ore is processed in two main stages. In the first stage *Pig Iron* is produced in a blast furnace. This type of iron is weak and brittle due to the high carbon content (4%) and is of little use in industry. The Pig Iron therefore needs to be processed further to reduce carbon in the steel. The main processes used are: (i) the Bessemer process, (ii) the basic oxygen process and (iii) the open hearth process. Mild Steel, Medium and High Carbon Steels can be produced from these processes.

2.0 Describing The Various Types Of Heat Treatments On Steel

Key Learning Points

Advantages of heat treatment: improvement of the material properties, improved machineability, increased hardness, toughness. Heat treatment processes: hardening, tempering, annealing and normalising. Effect of cooling rate on hardness. Carbon inducement, temperature range, depth of case, time required and critical range. Iron carbon equilibrium diagram, transformation range, carbon granules. Process planning: sequence of operations, use of technical handbooks, analysis of new data.

2.1 Advantages Of Heat Treatment: Improvement Of The Material Properties, Improved Machineability, Increased Hardness, Toughness

Heat treatment is a process where the steel is heated in a furnace and cooled in a controlled manner, in order to produce the required mechanical properties. Some of the most common heat treatments are as follows:

Annealing – Softens the steel in order to make it easier to machine.

Hardening – Hardens the steel so that it can cut other metals and resist wear.

Tempering – Removes the brittleness in the steel following the hardening process. It also removes some of the hardness and makes it tougher.

Normalising – Refines the structure of the steel following cold working such as hammering.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 13, *Materials*, sec. 13.5, *Heat treatment*, p. 217.
ISBN-13: 9780750660730

2.2 Heat Treatment Processes: Hardening, Tempering, Annealing And Normalising

Heat treatment processes: hardening, tempering, annealing and normalising.

Annealing Process – The steel is heated in a furnace to a temperature pending on the carbon content. It is held at this high temperature for a period of time. The furnace is then switched off and the steel is then cooled very slowly in the furnace.

Hardening Process - The steel is heated in a furnace to a temperature pending on the carbon content, which needs to be above 0.3%. It is held at this high temperature for a period of time. The steel is removed and cooled very quickly by quenching in water.

Tempering Process – Following the Hardening Process the steel is reheated in the furnace to a lower temperature then that of hardening. The steel is then removed and can be quenched or cooled slowly.

Normalising - The steel is heated in a furnace to a temperature pending on the carbon content. It is held at this high temperature for a period of time. It is removed and cooled in still air.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 13, *Materials*, sec. 13.5, *Heat treatment*, p. 217.
ISBN-13: 9780750660730

2.3 Effect Of Cooling Rate On Hardness

When the steel is cooled very quickly by quenching, it hardens the steel. When it is cooled slowly in the furnace it anneals the steel and when it is cooled in air it normalises the steel.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 13, *Materials; Hardening*, p. 219.
ISBN-13: 9780750660730

2.4 Carbon Inducement, Temperature Range, Depth Of Case, Time Required And Critical Range

Case hardening is achieved by packing the steel component into a steel box along with a carbonising media. The box is sealed with fireclay and heated to 950ºC for up to 5 hours. The length of time will depend on the depth of case required.

Ref: Timings, R.L. 1998, *Manufacturing technology*, vol. 1, 3rd edn, Pearson Education Limited, chapter 1, *Heat treatment processes; Case-hardening*, p. 268.
ISBN-13: 9780582356931

2.5 Iron Carbon Equilibrium Diagram, Transformation Range, Carbon Granules

When steel is heated in a furnace the internal grain structure begins to change at a particular temperature. This is called the lower critical range, which is about 700ºC. As the steel is heated further the structure continues to change until the upper critical range is reached. This temperature varies depending on the carbon content. If at this stage the steel is cooled by quenching, the structure is frozen in this state. The steel is then hardened.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 13, *Materials*, sec. 13.5, *Heat treatment*, p. 217.
ISBN-13: 9780750660730

2.6 Process Planning: Sequence Of Operations, Use Of Technical Handbooks, Analysis Of New Data

Job planning is important prior to starting any task. The drawing should first be studied and understood. The drawing can initially be used to calculate the material requirement for the component to be manufactured. The sequence of operations should be planned so as to minimise the number of setups on the lathe, milling machine and surface grinder.

Cutters, tools and equipment should be checked prior to starting the machining operations to ensure that the cutters are the correct size and in good condition and also that tools and equipment are in good working order.

Technical handbooks and data charts can be used, for example, when calculating speeds and feeds for the cutters, clearances between the punch and the die, heat treatment temperatures. It is also important to keep up to date with new developments in industry, such as new materials, equipment and processes. This information can be found in text books, manufactures catalogues and data sheets, engineering magazines and on the internet.

3.0 Describing The Properties Of A Range Of Non-Ferrous Metals

Key Learning Points

Co-efficient of linear expansion of metals, graphing relationship between increase in temperature and expansion.

3.1 Co-Efficient Of Linear Expansion Of Metals, Graphing Relationship Between Increase In Temperature And Expansion

The Coefficient of linear expansion is the amount by which a material expands when the temperature is raised one degree.

Increase in length = Original Length x Temperature Rise x Coefficient of linear expansion

Different metals expand and contract by different amounts, e.g. Copper expands at a greater rate then Iron.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 13, *Materials*, p. 211.
ISBN-13: 9780750660730

4.0 Safety Precautions To Be Adhered To When Heat Treating Steel

Key Learning Points

Handling and transformation of materials in a hot surface, dangers of the presence of water.

4.1 Handling and transformation of materials in a hot surface, dangers of the presence of water

When using the furnace to heat treat metals, it is important to wear protective gloves, clothes and safety glasses and face protection. Water will instantly start to boil and bubble up when a steel workpiece is plunged and quenched.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 1, *Safe practices*.
ISBN-13: 9780750660730

5.0 Hardening And Tempering Components Utilising Heat Treatment Charts

Key Learning Points

Hardening, tempering and annealing of a steel component to the required level.

5.1 Hardening, Tempering And Annealing Of A Steel Component To The Required Level

When steel is being hardened and tempered it is important to know temperature of the metal, so that it can be quenched or cooled at the required temperature. Charts are available that show the critical temperature range that the steel needs to reach for a particular carbon content. The furnace is normally fitted with a thermocouple pyrometer to measure the temperature of the furnace. To get a rough indication of the temperature of the steel its interesting to know that as the steel is heated in the furnace it changes colour, from a pale straw colour at 230ºC through to a blue colour at 300ºC. The variations in colour, which is caused by surface oxidation, can be used to give approximate indication of the temperature. A colour chart is available showing the various colours and the corresponding temperature.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 13, *Materials*, p. 217.
ISBN-13: 9780750660730

6.0 Identifying The Uses And/Or The Alternatives To Case Hardened Materials

Key Learning Points

Case hardening methods and applications. Procedure for case hardening (pack method). Alternative to case hardening: nitriding, cyaniding, flame hardening, induction hardening.

6.1 Case Hardening Methods And Applications

In order to heat treat steel it needs to have a carbon content of 0.3% or higher. Steel with a carbon content of 0.1 to 0.3% is called mild steel, which can be hardened by case hardening. This will result in a component with a hard wear resistant external surface and a tough interior.

Ref: Timings, R.L. 1998, *Manufacturing technology*, vol. 1, 3rd edn, Pearson Education Limited, chapter 1, *Heat treatment processes; Case-hardening*, p. 268.
ISBN-13: 9780582356931

6.2 Procedure For Case Hardening (Pack Method)

Case hardening is achieved by packing the steel component into a steel box along with a carbonising media. The box is sealed with fireclay and heated to 950ºC for up to 5 hours. The length of time will depend on the depth of case required.

Ref: Timings, R.L. 1998, *Manufacturing technology*, vol. 1, 3rd edn, Pearson Education Limited, chapter 1, *Heat treatment processes; Case-hardening*, p. 268.
ISBN-13: 9780582356931

6.3 Alternative To Case Hardening: Nitriding, Cyaniding, Flame Hardening, Induction Hardening

The salt bath furnace can be used to heat treat steel. The components are suspended in the molten salts during heat treatment. Types of salts that that can be used are nitrite based salts, chloride based salts and cyanide based salts.

Ref: Timings, R.L. 1998, *Manufacturing technology*, vol. 1, 3rd edn, Pearson Education Limited, chapter 1, *Heat treatment processes*, figs. 8.12, 8.13, p. 278.
ISBN-13: 9780582356931

Components can also be heat treated by rapidly heating the component with an oxyacetylene flame, which will heat the surface but not the core. The component is then quenched.

Ref: Timings, R.L. 1998, *Manufacturing technology*, vol. 1, 3rd edn, Pearson Education Limited, chapter 1, *Heat treatment processes*, fig. 8.6, p. 271.
ISBN-13: 9780582356931

A component can also be heated by electromagnetic induction, whereby the coil is placed over the component and the electric current causes the component to heat up. The component can then be sprayed to cool it.

Ref: Timings, R.L. 1998, *Manufacturing technology*, vol. 1, 3rd edn, Pearson Education Limited, chapter 1, *Heat treatment processes*, fig. 8.7, p. 272.
ISBN-13: 9780582356931

Summary

The origin of steel and steel production: Iron is an element that is extracted from iron ore, which is mined in various parts of the world. In order to produce steel, the iron ore is processed in two main stages. In the first stage *Pig Iron* is produced in a blast furnace. This type of iron is weak and brittle due to the high carbon content (4%) and is of little use in industry. The Pig Iron therefore needs to be processed further to reduce carbon in the steel. The main processes used are: (i) the Bessemer process, (ii) the basic oxygen process and (iii) the open hearth process. Mild Steel, Medium and High Carbon Steels can be produced from these processes.

Describing the various types of heat treatments on steel: Heat treatment is a process where the steel is heated in a furnace and cooled in a controlled manner, in order to produce the required mechanical properties. Some of the most common heat treatments are, Annealing, Hardening, Tempering and Normalising.

Describing the properties of a range of non-ferrous metals: The Coefficient of linear expansion is the amount by which a material expands when the temperature is raised one degree.

Safety precautions to be adhered to when heat treating steel: When using the furnace to heat treat metals, it is important to wear protective gloves, clothes and safety glasses and face protection.

Hardening and tempering components utilising heat treatment charts: When steel is being hardened and tempered it is important to know temperature of the metal, so that it can be quenched or cooled at the required temperature. Charts are available that show the critical temperature range that the steel needs to reach for a particular carbon content. The furnace is normally fitted with a thermocouple pyrometer to measure the temperature of the furnace. To get a rough indication of the temperature of the steel its interesting to know that the steel is heated in the furnace it changes colour, from a pale straw colour at 230ºC through to a blue colour at 300ºC. The variations in colour, which is caused by surface oxidation, can be used to give approximate indication of the temperature. A colour chart is available showing the various colours and the corresponding temperature.

Identifying the uses and/or the alternatives to case hardened materials: In order to heat treat steel it need to have a carbon content of 0.3% or higher. Steel with a carbon content of 0.1 to 0.3% is called mild steel, which can be hardened by case hardening. This will result in a component with a hard wear resistant external surface and a tough interior. This is achieved by packing the steel component into a steel box along with a carbonising media. The box is sealed with fireclay and heated to 950ºC for up to 5 hours. The length of time will depend on the depth of of case required.

The salt bath furnace can be used to heat treat steel. The components are suspended in the molten salts during heat treatment. Types of salts that that can be used are nitrite based salts, chloride based salts and cyanide based salts.

Components can also be heat treated by rapidly heating the component with an oxyacetylene flame, which will heat the surface but not the core. The component is then quenched.

A component can also be heated by electromagnetic induction, whereby the coil is placed over the component and the electric current causes the component to heat up. The component can then be sprayed to cool it.

Suggested Exercises

1. Explain the heat treatment processes of Annealing, Hardening, Tempering and Normalising.
2. Explain the heat treatment processes of case-hardening.
3. What is the coefficient of linear expansion?
4. What safety precautions should you take when heat treating and quenching steel parts.
5. In order to heat treat steel, what is the minimum carbon content that it should have.

Questions

1. What type of furnace is used to extract iron form iron ore and what is it called at this stage at this stage of the process?
2. Explain the following: Annealing, Hardening and Tempering.
3. Explain briefly what happens when tool steel is (i) quenched quickly or (ii) cooled slowly.
4. In the heat treatment process, what happens to tool steel if it is quenched when the steel is between the lower and upper critical ranges.
5. What heat treatment process is used to harden low carbon steel such as mild steel.

Answers

1. The blast furnace is used to extract iron from iron ore. The iron at this stage is called Pig Iron.
2. Annealing– Softens the steel in order to make it easier to machine.
   Hardening– Hardens the steel so that it can cut other metals and resist wear.
   Tempering – Removes the brittleness in the steel following the hardening process. It also removes some of the hardness and makes it tougher.
3. (i) When the tool steel is cooled very quickly by quenching, it hardens the steel. (ii) When it is cooled slowly in the furnace it anneals the steel and when it is cooled in air it normalises the steel.
4. If at this stage the steel is cooled by quenching, the structure is frozen in this state. The steel is then hardened.
5. Case hardening is used to heat treat low carbon steel such as mild steel.

Recommended Additional Resources

Reference Books

Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology.

ISBN-13: 9780750660730

Bird, John 2005, *Basic engineering mathematics*, 4th edn, Elsevier Science & Technology.

ISBN-13: 9780750665759

Timings, R.L. 1998, *Manufacturing technology*, vol. 1, 3rd edn, Pearson Education Limited.

ISBN-13: 9780582356931