Preface

The microstructures can tell the properties, quality, and the characteristics of metals. Metals with different compositions and different heat treatment condition will be different in microstructures. These set of specimens contains various kinds of ferrous metal in various conditions. These specimens can be used as the reference in studying of Metallurgy, Foundry, Heat Treatment, and Manufacturing Processes, etc.

There are 30 pieces of specimen in this set. Each specimen is prepared, etched, and coated with transparency coating material to protect the specimen surface and to be able to be seen under microscope, without any cleaning process. The specimens were kept in three wooden boxes, 10 pieces each. The data and specimen descriptions and micro-photographs are prepared and combined as a book and supplied together with the specimens.
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1. General Background and Introduction

1.1 General Engineering Materials:

Engineering materials can be classified into two classes, Metal and Non-metal.

A Metal: an element that has several metallic properties as the followings:
1. Shiny appearance.
2. Give sonorous tone when struck.
4. High malleability (can be rolled or pressed into shape).
5. High ductility (can be drawn into wire).
6. With possible emission of electrons when heated (thermionic effect) or when the surface is struck by light (photoelectric effect).
7. Hard and heavy.
8. Not transparent.

All metals have some of these properties. Some metals have every one of these properties. There are about 70 elements are classified as metals: e.g. Fe, Cr, Ni, Mg, Al, Cu etc.

A Non-metal: an element with certain physical and chemical properties opposite to those of metals. Non-metals accept electron to form negatively charged ions.

There are about 20 elements are classified as metals: e.g. S, P, C, Si and F etc.

The metals can be divided into two classes: Non-ferrous metals and Ferrous metals which are also divided into many sub-classes as shown in Fig.1.

The Non-metals are Polymers and Ceramic are out of the scope of this book.

All specimens mentioned in this book are Ferrous metals and picked up from Carbon steels, Low alloy steels, Cast irons, Tool steels, and Cast steels.

1.2. Steel Making

Carbon steels, Low alloy steels, and Tool steels are made as shown in Fig.2. Cast irons and Cast steels are made as shown in Fig.3.

1.3. Specimen Selection

The specimen were cut from the specified round bars and flat bars of Carbon steels, Low alloy steels, and Tool steels and heat treated according to the specified processes.

The specimen of Cast iron(gray cast iron, nodular iron, and Bainitic Ductile Iron) were casted by using induction furnace and sand mold, then heat treated according to the specified processes.

Specimen No.29,30 are special alloy cast steel, also were casted in the induction furnace with high percentage of Mn addition and good quality control. No.29 is in as cast condition and No.30 is after annealing.

1.4. Specimen preparation

Every specimen was prepared according to the processes shown in Fig.4.

1.5. Heat treatment processes

General heat treatment processes are shown in Fig.5 and the heat treatment processes applied for each specimens is shown in each data sheet for each specimen.
Note: Ladle Metallurgy is used to control condition within the ladle to improve productivity in preceding and subsequent processing steps and the quality of the final product. These conditions can include temperature, pressure, chemistry, and momentum through stirring.

Note: A modification of the BOP is the Q-BOP which the oxygen and other gas are blown in from the bottom rather than the top as shown.
Molten steel must solidify before it can be made into finished products in an infinite variety, considering chemistry, properties, and sizes.

Flat rolled products are rolled from slabs by using sets of cylindrical rolls.

Grooved rollers squeeze billets into different cross-sections (round, angles, etc.) in a sequence of operations.

Piercing is the process used to make seamless pipe and tube.

Set of grooved rolls are used to roll brooms into heavy beam for construction or for rails.

A small but significant percentage of heated ingot steel is squeezed in forging presses to make large shafts for power plants, nuclear plants, nuclear plant components, and other products.
Fig. 3  Casting processes
### Specimen preparation

**1. Cutting**
- coolant
- cutting wheel
- specimen

**2. Mounting**
- fixed piston
- moving piston
- bekalite
- specimen

**3. Grinding**
- coolant
- sand paper
- specimen
- grinding wheel

**4. Polishing**
- coolant
- polishing medium (Al₂O₃ suspension)
- specimen
- polishing cloth
- polishing wheel

**5. Etching**
- etchant
- specimen
- watch glass
- (Keep the specimen moving during etching)

**6. Examination**
- ccd camera
- metallurgical microscope
- computer set and printer

**7. Micro-photography**

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### Equipment:

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</thead>
<tbody>
<tr>
<td>Lab cut-off machine</td>
<td>Hot mounting machine</td>
<td>Grinding machine</td>
<td>Polishing machine</td>
<td>Watch glass</td>
<td>Metallurgical microscope, CCD camera, and specimen leveller.</td>
</tr>
<tr>
<td>Resin bonded, both soft type (for hard specimen) and hard type (for soft specimen)</td>
<td>Phenolic resin (Bekelite) or Acrylic resin (transparent type)</td>
<td>Water proof sand paper grit No.240, 400, 800, 1200, and 2400</td>
<td>Polishing cloth and water suspended Alumina powder, 0.3 micron</td>
<td>2.1 Reagent 7a. 2.2 Nital 3 %</td>
<td>50x, 100x, 200x, 500x. and 1000x.</td>
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<td>170-180°C</td>
<td>Water</td>
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<td>15-30 seconds</td>
<td>After etching, the specimen must be rinsed with flowing water and washed with alcohol and immediately blown with hot air.</td>
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**Note:**

- The specimen must be well selected and may be round square or other irregular shape.
- The cutting must be carried out carefully and enough coolant to prevent overheating during cutting.
- The grinding must start from the coarse sand paper and change to finer sand paper.
- Before changing to the finer sand paper, the grinding line from the previous sand paper must be disappeared and the new grinding lines must be in the same direction. And before starting the new sand paper, the specimen and hands must be clean.
- Before polishing, the specimen and hands must be clean.
- During the polishing, the specimen must be kept clockwise, and counter-clockwise to prevent comet tail.
- The water must be used together with the polishing powder.
- After polishing, the specimen must be rinsed with water and alcohol and dry with hot air.

**2.1 Reagent 7a:**
- Nitric acid (HNO₃): 3 cc
- Alcohol: 97 cc

**2.2 Nital 3 %:**
- Reagent 7a: 3 g potassium metabisulfite
- 1 g sulfamic acid
- 100 ml Distilled water

**2. The magnification:**
- 50x, 100x, 200x, 500x. and 1000x.

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Fig. 4 Specimen preparation
## Record of Microstructures

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<thead>
<tr>
<th>Specimen No.: 1</th>
<th>Specimen name</th>
<th>Material</th>
<th>Condition</th>
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<th>P</th>
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<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
<th>Co</th>
<th>W</th>
<th>Others</th>
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<td>0.15-0.35</td>
<td>0.30-0.60</td>
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<th>RUSSIA</th>
<th>CHINA</th>
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### Characteristics:
Most widely used of several grades containing about 0.20% carbon. Available in a variety of product forms. Excellent forgeability and weldability. No preheating and post heating required before or after welding. Machinability is notoriously poor. Wildly used as a carburizing steel.

### Applications:
Parts for case hardened condition where core strength is not critical, and shaft for large section that are not highly stressed, case hardened gears pins and chain.

### Heat treatment guide

<table>
<thead>
<tr>
<th>Description</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Through hardening</th>
<th>Carburizing</th>
<th>Tempering</th>
<th>Carbonitriding</th>
<th>Tempering</th>
<th>Nitriding</th>
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<tbody>
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<td>Because of low carbon</td>
<td>870-955</td>
<td>200-250</td>
<td>850-870</td>
<td>200-250</td>
<td>Nitriding is not recommended.</td>
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<td>Soaking time, min.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>and no alloying element</td>
<td>depend on case depth.</td>
<td>2 hrs min.</td>
<td>depend on case depth.</td>
<td>2 hrs min.</td>
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<td>Quenching medium</td>
<td>air or nitrogen</td>
<td>Through hardening is not oil</td>
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### Final heat treatment process of this specimen

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<th>°C preheat</th>
<th>870</th>
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</table>

### Process:
The specimen is heated to 880°C for 60 min., the steel microstructures will transform to austenite, then cooldown slowly in the furnace austenite will transform to ferrite and pearlite. The steel will be softened, better machinability, better cold workability, and improve dimensional stability, etc.

### Microstructures

**Photo.1:** 200x, Microstructures consist of Ferrite (yellow, blue, and purple), and Pearlite (brown), small black dots are inclusions remain in steel.

**Photo.2:** 1000x, same as in Photo. 1 but higher magnification. Brown area can be clearly seen Cementite and Ferrite in Pearlite. Grain boundaries are also clearly seen.

**200x**

**1000x**
Photo 3: 1000x, Same as in Photo 1,2 but in large area. The microstructures consist of Ferrite (blue, green, purple, yellow) and Pearlite (brown area with Cementite strips on Feerite).
### Record of Microstructures

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</table>
The original microstructures of the steel are Ferrite and Pearlite. After carburization, carbon diffused through the surface to the core. The structure at the surface becomes Pearlite which consists of Cementite, Fe₃C, and Ferrite (see Photo.7). Below the surface, the structures consist of Pearlite and Ferrite (see Photo.8) and at the core, the structures are unchanged, it still be Pearlite and Ferrite as in the original condition (see Photo.9).
**Record of Microstructures**

<table>
<thead>
<tr>
<th>Specimen No.: 3</th>
<th>Specimen name</th>
<th>Material</th>
<th>Condition</th>
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</thead>
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<td>Ferrous Metal</td>
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<td>Carburized, quenched and tempered</td>
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<th>Cr</th>
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<th>Ni</th>
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<th>CHINA</th>
<th>SWEDEN</th>
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</table>

**Characteristics:**

Most widely used of several grades containing about 0.20% carbon. Available in a variety of product forms. Excellent formability and weldability.

No preheating and post heating required before or after welding. Machinability is notably poor. Widely used as a carburizing steel.

**Applications:**

Parts for case hardened condition where core strength is not critical, and shaft for large section that are not highly stressed, case hardened gears pins and chain.

**Heat treatment guide**

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Through hardening</th>
<th>Carburizing</th>
<th>Tempering</th>
<th>Carbonitriding</th>
<th>Tempering</th>
<th>Nitriding</th>
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<tr>
<td>870-955</td>
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**Heat treatment process of this specimen**

- Temperature: 920°C for 180 min.
- Atmosphere controlled furnace with carbon potential 0.9%. C atom diffused into specimen surface and combined with Fe to form Fe₃C (Cementite).
- Process: The specimen is heated to 920°C for 180 min. in atmosphere controlled furnace with carbon potential 0.9%. C atom diffused into specimen surface and combined with Fe to form Fe₃C (Cementite) which gives more pearlite and less ferrite. After hardened and tempered, pearlite and ferrite transformed to austenite and then martensite accordingly. Tempered martensite + P + F will be achieved finally.

**Microstructures**

- Photo. 10: 50x, The specimen was carburized, quenched, and tempered. Pearlite at the surface and below surface transformed to Martensite (left, colorfull area).
- Photo. 11: 1000x, At the case area, the acicular or needle like structure (Martensite) will be seen (purple, green, and brown).
Photo.12 shows the microstructures from the surface of low carbon steel to the core after carburized, quenched, and tempered. The case with green, purple, and yellow is Martensite (see Photo.13). Between case and core are Martensite and Ferrite (see Photo.14). At the core, the microstructures remain the same as the original, Pearlite and Ferrite, some Pearlite may transfer to Martensite, but Ferrite still unchanged (see Photo.15).
### Specimen Data

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<thead>
<tr>
<th>Specimen No.: 4</th>
<th>Specimen name</th>
<th>Material</th>
<th>Condition</th>
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<tbody>
<tr>
<td></td>
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### Chemical Composition

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<td>0.18-0.23</td>
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### Similar Steels

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<td>CS1020</td>
</tr>
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</table>

### Characteristics:

Most wildly used of several grade s containing about 0.20% carbon. Available in variety of product forms. Excellent forgability and weldability. No preheating and post heating required before or after welding. Machinability is notably poor. Wildly used as a carburizing steel.

### Applications:

Parts for case hardened condition where core strength is not critical, and shaft for large section that are not highly stressed, case hardened gears, pins and chain.

### Heat Treatment

<table>
<thead>
<tr>
<th>Description</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Through hardening</th>
<th>Carburizing</th>
<th>Tempering</th>
<th>Carbonitriding</th>
<th>Tempering</th>
<th>Tempering</th>
<th>Nitriding</th>
</tr>
</thead>
<tbody>
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<td>925</td>
<td>Because of low carbon</td>
<td>Temperature, °C</td>
<td>870-955</td>
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<td>850-870</td>
<td>200-250</td>
<td>Nitriding not recommended.</td>
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<tr>
<td>Soaking time, min.</td>
<td>1/2 hr./25 mm.+1 hr.</td>
<td>and no alloying element</td>
<td>Soaking time, min.</td>
<td>2 hrs min.</td>
<td>depend on case depth.</td>
<td>2 hrs min.</td>
<td>depend on case depth.</td>
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<td>Through hardening is not</td>
<td>Quenching medium</td>
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<td>air</td>
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<td>Hardness</td>
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<td>55-60 HRC</td>
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</table>

### Final Heat Treatment Process of This Specimen

- **Process**: The specimen is heated to 850°C for 180 min. in atmosphere controlled furnace with carbon potential 0.9% and some of NH₃ gas. C and N atom will diffuse into specimen surface and form both cementite and nitride compounds in surface area. After quenched and tempered, tempered martensite+nitride+pearlite+ferrite will be achieved.

### Microstructures

**Photo.16**: 50x, Cross-sectioned shows the microstructures from surface to core of the specimen. Dark case is Martensite, colorfull core are Pearlite and Ferrite.

**Photo.17**: 1000x, Photo taken at the case, needlelike structure, Martensite.
Photo. 18 shows the microstructures from the surface to the core of low carbon steel after carbonitrided, quenched and tempered. The case consists of Martensite (see Photo. 19). Between the case and core, consists of Martensite and Ferrite (see Photo. 20). And at the core, the original microstructures, Pearlite and Ferrite still remain (see Photo. 21).
Characteristics: When heat treated, this steel yields a high surface hardness, combined with relative good toughness. This grade also has good forging characteristics. It is shallow hardening, however, and useful section size is limited. Parts made from AISI1055 steel requiring strength are oil quenched; parts requiring high hardness are water quenched.

Applications: Battering tools, hot upset forging dies, ring rolling tools, wear resistant parts, hand tools, and parts for agricultural implements with high strength and low cost.

Heat treatment guide:
- Temperature, °C: 900
- Soaking time, min.: 1/2 hr./25 mm.+1 hr.
- Quenching medium: air or nitrogen
- Hardness: 180-200 HB
- Process: The specimen is heated to 830°C, soaking time should be at 1/2 hour per inch of thickness plus 1 hour minimum and furnace cool to 650°C at a rate not exceed 28°C per hour. Microstructures consist of pearlite and ferrite. Low hardenability, good forgeability, poor machinability, not recommend for welding.
Photo 24: 500x. Same as in Photo 23, but in the larger area. The microstructures consist of Pearlite and Ferrite.
**Characteristics:** When heat treated, this steel yields a high surface hardness, combined with relative good toughness. This grade also has good forging characteristics. It is shallow hardening, however, and useful section size is limited. Parts made from AISI1055 steel requiring strength are oil quenched; parts requiring high hardness are water quenched.

**Applications:** Battening tools, hot upset forging dies, ring rolling tools, wear resistant parts, hand tools, and parts for agricultural implements with high strength and low cost.

**Heat treatment guide:**

- **Temperature, °C:** Heat treat 830°C
- **Quenching medium:** Air or nitrogen, furace cool, oil or water
- **Soaking time, min.:** 1/2hr/25 mm.+1 hr.

**Final heat treatment process of this specimen:**

- **Temperature:** 830°C
- **Quenching medium:** Water
- **Soaking time:** 30 min.

**Microstructures:**

- The specimen is heated to 830°C, pearlite and ferrite transformed to austenite. Some cementite remained, and then quenched in water, austenite then transformed to martensite. The martensite is untempered martensite, high stress, high hardness, brittle, not suitable for any application. Some Ferrite retained because of low hardenability of steel.
Photo 27: 1000x, Same as in Photo 26, but in larger area. The microstructures consist of Martensite and un-changed Ferrite.
### Characteristics:
When heat treated, this steel yield a high surface hardness, combined with relative good toughness. This grade also has good forging characteristics. It is shallow hardening, however, and useful section size is limited. Parts made from AISI1055 steel requiring strength are oil quenched; parts requiring high hardness are water quench.

### Applications:
Battering tools, hot upsetting forging dies, ring rolling tools, wear-resistant parts, hand tools, and parts for agricultural implements with high strength and low cost.

### Heat treatment guide

<table>
<thead>
<tr>
<th>Description</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
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<tbody>
<tr>
<td>Temperature, °C</td>
<td>900</td>
<td>830</td>
<td>830</td>
<td>250-450</td>
<td>850-870</td>
<td>200-250</td>
<td>Nitriderg is not recommended.</td>
<td></td>
</tr>
<tr>
<td>Soaking time, min.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>depend on case depth.</td>
<td>2 hrs min.</td>
<td>depend on case depth.</td>
<td>2 hrs min.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quenching medium</td>
<td>air or nitrogen</td>
<td>furace cool</td>
<td>oil or water</td>
<td>air</td>
<td>oil</td>
<td>air</td>
<td></td>
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</tr>
<tr>
<td>Hardness</td>
<td>180-200 HB</td>
<td>197 HB</td>
<td>60-64 HRC</td>
<td>60-64 HRC</td>
<td>60-62 HRC</td>
<td>60 HRC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Final heat treatment process of this specimen

- **Preheat**: 830°C for 500 min.
- **Quench**: Cool in air or nitrogen for 60 min.
- **Temper**: 620°C for 300 min.

**Process:**
The specimen is heated to 830°C, pearlite and ferrite transformed to austenite, and then quenched in water, austenite then transformed to martensite. The as quench martensite is hard and brittle. The specimen was tempered at 300°C for 120 minutes, martensite transformed to tempered martensite with lower hardness, higher toughness. The hardness can be controlled by varying temperature.

### Microstructures

**Photo.28:** 100x, Medium carbon steel, quenched and tempered, microstructures consist of martensite with a medium-sized, blocky structure.

**Photo.29:** 1000x, Same as in Photo.28, but in higher magnification. Tempered Martensite are clearly seen.
Photo.30: 1000x. Same as in Photo.29, but in larger area. The microstructures consist of tempered martensite.
The higher carbon of 1095 steel provides maximum surface hardness with improved wear resistance and high strength. There is, however, a loss of toughness. Because cold forming methods are not suitable for this steel, uses are limited to flat stampings and springs coiled from small diameter wire.

Applications:
Edge tools, wear-resistant parts, mower knives, scraper blades, discs, etc.

Heat treatment guide:

<table>
<thead>
<tr>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
<th>Austempering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
<td>855</td>
<td>800</td>
<td>800</td>
<td>370-675</td>
<td>800</td>
</tr>
<tr>
<td>Soaking time, min.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>2 hrs min.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td></td>
</tr>
<tr>
<td>Quenching medium</td>
<td>air or nitrogen</td>
<td>furnace cool</td>
<td>oil or water</td>
<td>air</td>
<td>salt bath at 315°C, 2 hrs., air cool</td>
</tr>
<tr>
<td>Hardness</td>
<td>269-290 HB</td>
<td>269-290 HB</td>
<td>63-66 HRC</td>
<td>27-43 HRC</td>
<td>63-66 HRC</td>
</tr>
</tbody>
</table>

The specimen is a hyper-eutectoid steel. The specimen was reheated to 800 °C for 60 min. for austenitizing, then slowly cooled down the specimen in the furnace at the cooling rate not exceed 28°C per hour until 650°C then air cooled to room temperature. The final microstructure are pearlite and carbide. If the surface is not well protected, carbon content will decrease (decarburization).

Microstructures:

Photo.31: 100x, The microstructures consist of Pearlite and carbides

Photo.32: 1000x, Same as in Photo.31, but in higher magnification. The matrix is Pearlite. White particles are carbides or Cementite, Fe₃C.
Photo.33: 1000x, Same as in Photo.32, but in larger area. Microstructures consist of Pearlite matrix and Carbides particles.
Characteristics: The higher carbon of 1095 steel provides maximum surface hardness with improved wear resistance and high strength. There is, however, a loss of toughness. Because cold forming methods are not suitable for this steel, uses are limited to flat stampings and springs coiled from small diameter wire.

Applications: Edge tools, wear-resistant parts, mower knives, scraper blades, discs, etc.

Heat treatment guide

<table>
<thead>
<tr>
<th>Description</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
<th>Austempering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
<td>855</td>
<td>800</td>
<td>800</td>
<td>370-675</td>
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<tr>
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<td>furnace cool</td>
<td>oil or water</td>
<td>air</td>
<td>salt bath at 315°C, 2 hrs., air cool</td>
<td></td>
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<tr>
<td>Hardness</td>
<td>269-290 HB</td>
<td>269-290 HB</td>
<td>63-66 HRC</td>
<td>27-43 HRC</td>
<td>63-66 HRC</td>
<td></td>
</tr>
</tbody>
</table>

The specimen was heated to 800°C for austenitizing and soaked for 60 minutes, pearlite will transform to austenite, and some cementite may remain. Then quench in water, austenite will transform to martensite, needlelike structure, high stress, hard and brittle. High carbon steel in this condition is not suitable for any application because of brittleness.

Microstructures

Photo.34: 100x, The microstructures consist of martensite and carbides.

Photo.35: 1000x, Same as in photo.34, but in higher magnification. Acicular structure is Martensite and white particles are carbides. Light blue area are retained Austenite.
Photo.36: 1000x, Same as in Photo.35, but in larger area. The microstructures consist of Martensite, Carbides and retained Austenite.
**Chemical composition**

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<th>Si</th>
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<th>Co</th>
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<td>0.050max</td>
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**Similar steels**

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<td>DIN</td>
<td>KRUPP</td>
<td>AFNOR</td>
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<td>PN84028</td>
<td>SS14</td>
<td>JIS G4801</td>
<td>UNI3545</td>
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<td>A510,A556</td>
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<td>CX100</td>
<td>C98</td>
<td>DS105</td>
<td>1870</td>
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**Characteristics:**

The higher carbon of 1095 steel provides maximum surface hardness with improved wear resistance and high strength. There is, however, a loss of toughness. Because cold forming methods are not suitable for this steel, uses are limited to flat stampings and springs coiled from small diameter wire.

**Applications:**

Edge tools, wear-resistant parts, mower knives, scraper blades, discs, etc.

**Heat treatment guide**

- **Temperature, °C**
  - Normalizing: 855
  - Annealing: 800
- **Quenching medium**
  - Normalizing: 800
- **Final heat treatment process of this specimen**
  - 30 min. preheat 500°F, 60 min. at 300°F air cooling, 30 min. in water

**Microstructures**

Photo.37: 100x, The microstructures consist of Martensite, and carbides.

Photo.38: 1000x. Same as in Photo.37, but in higher magnification. The matrix is Martensite, White particles are carbides.
Photo 39: 1000x. Same as in Photo 38, but in larger area. The microstructures consist of Martensite, and carbides.
Specimen No.: 11

**Chemical composition:**
- C: 0.90-1.03
- Si: 0.15-0.35
- Mn: 0.30-0.50
- P: 0.04 max
- S: 0.050 max
- Cr: -
- Mo: -
- Ni: -
- V: -
- Ti: -
- Co: -
- W: -
- Others: -

**Similar steels:**
- USA
- GERMANY
- FRANCE
- INDIA
- POLAND
- SWEDEN
- JAPAN
- ITALY
- AUSTRALIA
- UK

**AISI/SAE**
- A510
- A586

**Characteristics:**
The higher carbon of 1095 steel provides maximum surface hardness with improved wear resistance and high strength. However, there is a loss of toughness. Because cold forming methods are not suitable for this steel, uses are limited to flat stampings and springs coiled from small diameter wire.

**Applications:**
- Edge tools, wear-resistant parts, mower knives, scraper blades, discs, etc.

**Heat treatment guide:**
- **Normalizing:**
  - Temperature, °C: 885
  - Soaking time, min.: 1/2 hr./25 mm.+1 hr.
  - Quenching medium: air or nitrogen

- **Annealing:**
  - Temperature, °C: 800
  - Soaking time, min.: 1/2 hr./25 mm.+1 hr.
  - Quenching medium: furnace cool

- **Full hardening:**
  - Temperature, °C: 800
  - Soaking time, min.: 1/2 hr./25 mm.+1 hr.
  - Quenching medium: oil or water

- **Tempering:**
  - Temperature, °C: 370-675
  - Hardness: 63-66 HRC

- **Austempering:**
  - Temperature, °C: 800
  - Hardness: 63-66 HRC

**Final heat treatment process of this specimen:**
- **Preheat:**
  - Temperature, °C: 500
  - Soaking time, min.: 30 min.

**Process:**
The specimen is a hyper-eutectoid steel. The specimen was reheated to 800°C for 60 min. for austenitizing, then slowly cooled down the specimen in the furnace at the cooling rate not exceed 28°C per hour until 650°C, then air cooled to room temperature. The final microstructure are pearlite and carbide. If the surface is not well protected, carbon content will decrease (decarburization).

**Microstructures:**
- Photo. 40: 100x, The specimen is un-etched for inclusion investigation. Black dots and
  - 40
  - 100x
- Photo. 41: 1000x, Same as in Photo.40, but in higher magnification. Brown particles are non-metallic inclusion. These inclusions remained from the melting processes.
Photo 42: 1000x, The brown area are non-metallic inclusions. The specimen is un-etched.
### Characteristics and applications:
A medium carbon, Chromium-Molybdenum steel. Available as hot rolled and cold finished bar and seamless tube, this steel is for general purpose applications. Variations in heat treatment can obtain a broad range of strength and toughness. This steel has good hardenability, strength, wear resistance, toughness and ductility. In heat treated condition, it offers good strength and toughness for moderately stressed parts. It is available in forging quality, and aircraft quality.

#### Heat treatment guide

<table>
<thead>
<tr>
<th>Description</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
<th>Carbonitriding</th>
<th>Tempering</th>
<th>Nitriding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
<td>900</td>
<td>855</td>
<td>880</td>
<td>250-650</td>
<td>850-870</td>
<td>200-250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soaking time, min.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>2 hrs min.</td>
<td>depend on case depth.</td>
<td>2 hrs min.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quenching medium</td>
<td>air or nitrogen</td>
<td>furnace cool</td>
<td>oil or water</td>
<td>air or faster</td>
<td>oil</td>
<td>air</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>163-217 HB</td>
<td>217 HB</td>
<td>45-50 HRC</td>
<td>48-22 HRC</td>
<td>60-62 HRC</td>
<td>58-60 HRC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Final heat treatment process of this specimen

- **Process:** The specimen was heated at 855°C and soak for 60 minutes for austenitizing, the original microstructure will be transformed to austenite, then cooled down slowly in the furnace, austenite will be transformed to pearlite and ferrite. Strength and hardness decrease, ductility increases.
- **Microstructures:**

  - Photo.43:100x, The microstructures consist of Pearlite and Ferrite.
  - Photo.44:1000x, Same as in Photo.34, but in higher magnification. Dark brown area are Pearlite, light area are ferrite.
Photo. 45: 1000x. Same as in Photo. 44, but in larger area. Light area are Ferrite, dark area are Pearlite.
Record of Microstructures

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
<th>Co</th>
<th>W</th>
<th>Others</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.15-0.30</td>
<td>0.40-0.60</td>
<td>0.035 max</td>
<td>0.040max</td>
<td>0.80-1.10</td>
<td>0.15-0.25</td>
<td>-</td>
<td>-</td>
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Similar steels

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<th>Steel grade</th>
<th>USA</th>
<th>GERMANY</th>
<th>FRANCE</th>
<th>RUSSIA</th>
<th>CHINA</th>
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</thead>
<tbody>
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<td>AISI/SAE</td>
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<td>A510: A556</td>
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<td>S80C</td>
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</table>

Characteristics and applications:

A medium carbon, Chromium-Molybdenum steel. Available as hot rolled and cold finished bar and seamless tube, this steel is for general purpose applications. Variations in heat treatment can obtain a broad range of strength and toughness. This steel has good hardenability, strength, wear resistance, toughness and ductility. In heat treated condition, it offers good strength and toughness for moderately stressed parts. It is available in forging quality, and aircraft quality.

Heat treatment guide

<table>
<thead>
<tr>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
<th>Carbonitriding</th>
<th>Tempering</th>
<th>Nitriding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
<td>900</td>
<td>855</td>
<td>880</td>
<td>250-650</td>
<td>850-870</td>
<td>200-250</td>
<td>Nitriding is not recommended.</td>
</tr>
<tr>
<td>Soaking time, min.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>1/2hr./25 mm.+1 hr.</td>
<td>2 hrs min.</td>
<td>depend on case depth.</td>
<td>2 hrs min.</td>
<td>oil or air</td>
</tr>
<tr>
<td>Quenching medium</td>
<td>air or nitrogen</td>
<td>furnace cool</td>
<td>oil or water</td>
<td>oil or faster</td>
<td>air or oil</td>
<td>air</td>
<td>oil or nitrogen</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>163-217 HB</td>
<td>217 HB</td>
<td>45-50 HRC</td>
<td>48-22 HRC</td>
<td>60-62 HRC</td>
<td>58-60 HRC</td>
<td>80CS</td>
</tr>
</tbody>
</table>

Final heat treatment process of this specimen

- Temperature: 880°C
- Preheat: 500°C for 30 min.
- Annealing: 855°C for 1/hr.
- Full hardening: 880°C for 2 hrs.
- Tempering: 250-650°C for 2 hrs.
- Carbonitriding: 850-870°C for 2 hrs.
- Tempering: 600-620°C for 2 hrs.
- Nitriding: 800°C for 2 hrs.

Microstructures

Photo.46:100x, Microstructure after quenching and tempering is Martensite.

Photo.47:1000x, Same as in Photo.46, but in higher magnification. The structures are Martensite.

Specimen No.: 13

Specimen name: Ferrous Metal

Material: AISI 4130

Condition: Hardened by quenching and tempering

Microstructures after quenching and tempering are Martensite.
Photo 48: 500x. The microstructures are Martensite.
**Characteristics and applications:**
A high hardenability steel, higher in hardenability than other standard AISI grade. AISI 4340 steel is nickel-chromium-molybdenum alloy steel. It is normally heat treated by quenching in oil and tempering to the desired hardness. It exhibits good response to heat treatment and possesses a good combination of strength, ductility, and toughness in quenched and tempered condition. AISI4340 is found in aircraft and truck parts and some ordnance materials, and also for gear, shafts, die block, etc.

---

### Heat treatment guide

<table>
<thead>
<tr>
<th>Description</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
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<th>Tempering</th>
<th>Nitriding</th>
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</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
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<td>850-870</td>
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<td>Soaking time, min.</td>
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<td>depend on case depth.</td>
<td>2 hrs min.</td>
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<td>Quenching medium</td>
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<td>air</td>
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</tbody>
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**Final heat treatment process of this specimen**

- **Temperature:** 855°C
- **Preheat:** 500°C
- **Furnace cool:** 60°C
- **Time:** 30 min.

**Process:** The specimen was heated at 855°C and soak for 60 minutes for austenitizing, the original microstructure will be transformed to austenite, then cooled down slowly in the furnace, austenite will be transformed to pearlite and ferrite. Strength and hardness decrease, ductility increases.

---

**Microstructures**

**Photo.49:** 100x, Microstructures are Pearlite and ferrite.

**Photo.50:** 1000x, Same as in Photo.49, but in higher magnification. Light area are Ferrite, dark area are Pearlite. Fine bright particles are Carbides.
Photo 51: 500x, The microstructures are Pearlite and Ferrite. Fine bright particles are Carbides.
**Record of Microstructures**

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<th>Mn</th>
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<td>CHINA</td>
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</tbody>
</table>

**Characteristics and applications:** Cast irons are alloys of iron(Fe), carbon(C), and silicon(Si) in which more carbon is present than can be retained in solid solution in austenite at the eutectic temperature. The carbon that exceeds the solubility in austenite precipitates as flake graphites. Gray cast iron is used for many different types of parts in a very wide variety of machines and structures. For example: machine bed, motor housing, gear, pulley, wheel, etc.

<table>
<thead>
<tr>
<th>Heat treatment guide</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
<th>Carbonitriding</th>
<th>Tempering</th>
<th>Nitriding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
<td>Normalizing</td>
<td>885-925</td>
<td>790-900</td>
<td>755-790</td>
<td>250-650</td>
<td>Carbonitriding</td>
<td>gray cast iron is not recommended</td>
<td>- Nitriding is not recommended.</td>
</tr>
<tr>
<td>Soaking time, min.</td>
<td>Soaking</td>
<td>1hr./25 mm.+1 hr.</td>
<td>1hr./25 mm.+1 hr.</td>
<td>1hr./25 mm.+1 hr.</td>
<td>2 hrs min.</td>
<td>quenching medium</td>
<td>air or nitrogen</td>
<td>furnace cool oil or water recommended</td>
</tr>
<tr>
<td>Hardness</td>
<td>Hardness</td>
<td>163-217 HB</td>
<td>160-180 HB</td>
<td>45-50 HRC</td>
<td>48-22 HRC</td>
<td>manufacturing process of this specimen</td>
<td>The charges (consist of pig iron, cast iron scraps, steel scraps, FeSi, FeMn, flux) were charged into induction furnace and melted into liquid metal, then the molten metal was discharged into the crucible and then poured into prepared sand mould. Molten metal will be solidified and taken out of the sand mould. The casting was cut to specimen and ground, polished, un-etched to show graphite flakes.</td>
<td></td>
</tr>
</tbody>
</table>

**Record of Microstructures**

**Photo.52:100x,** Gray cast iron, un-etched, showing graphite flakes distribution

**Photo.53:1000x,** Same as in Photo.52, but in higher magnification, the dark gray scripts are graphite flakes.
Photo 54: 200x, Showing graphite flake distribution and orientation. Dark gray particles and scripts are graphite flakes. The matrix is un-revealed.
### Characteristics and applications:

Cast irons are alloys of iron (Fe), carbon (C), and silicon (Si) in which more carbon is present than can be retained in solid solution in austenite at the euteutic temperature. The carbon that exceeds the solubility in austenite precipitates as flake graphites. Gray cast iron is used for many different types of parts in a very wide variety of machines and structures. For example: machine bed, motor housing, gear, pulley, wheel, etc.

### Heat treatment guide

<table>
<thead>
<tr>
<th>Description</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
<th>Carbonitriding</th>
<th>Tempering Nitriding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
<td>885-925</td>
<td>790-900</td>
<td>755-790</td>
<td>250-650</td>
<td>Carbonitriding of gray cast iron is not recommended</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soaking time, min.</td>
<td>1 hr./25 mm.+1 hr.</td>
<td>1 hr./25 mm.+1 hr.</td>
<td>1 hr./25 mm.+1 hr.</td>
<td>2 hrs min.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quenching medium</td>
<td>air or nitrogen</td>
<td>furnace cool</td>
<td>oil or water</td>
<td>air or faster</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>163-217 HB</td>
<td>160-180 HB</td>
<td>45-50 HRC</td>
<td>48-22 HRC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Manufacturing process of this specimen

The charges (consist of pig iron, cast iron scraps, steel scraps, FeSi, FeMn, flux) were charged into induction furnace and melted into liquid metal, then the molten metal was discharged into the crucible and then poured into the sand mould. Molten metal will be solidified into solid (casting). The casting was cut, mounted, dround, polished, and etched to show both graphite flakes and matrix.

### Microstructures

Photo. 55: 100x, Gray cast iron, as cast, etched, showing graphite and matrix.

Photo. 56: 1000x, Same as in Photo. 55, but in higher magnification, dark scripts are graphite flakes, matrix are Pearlite and Ferrite.
Photo 57: Same as in photo 56, but in larger area. Dark gray branches are graphite flakes. The matrix consists of Pearlite (small lines of cementite and Ferrite), and Ferrite.
Characteristics and applications: Cast irons are alloys of iron(Fe), carbon(C), and silicon(Si) in which more carbon is present than can be retained in solid solution in austenite at the eutectic temperature. The carbon that exceeds the solubility in austenite precipitates as flake graphites. Gray cast iron is used for many different types of parts in a very wide variety of machines and structures. For example: machine bed, motor housing, gear, pulley, wheel, etc.

Heat treatment guide:
- Temperature, °C: 790-925
- Annealing: 790-900
- Full hardening: 755-790
- Tempering: 250-650
- Carbonitriding: 885-925
- Tempering: 790-900
- Nitriding: 755-790

Final processes of this specimen:
- Temperature, °C: 790
- Normalizing: 60
- Annealing: 300
- Full hardening: 160-180 HB
- Tempering: 163-217 HB
- Carbonitriding: 45-50 HRC
- Tempering: 48-22 HRC
- Nitriding: -

Process: The specimen was heated to 790°C for austenitizing. During austenitizing, the matrix which consist of pearlite and ferrite, will transform to austenite, graphite flakes still remain. After soaking at the temperature, the specimen was quenched in water, austenite transformed to martensite. The as quench microstructure consists of martensite and graphite. Martensite will be tempered martensite after tempering.
Acicular structures are Martensite, dark gray scripts are graphite flakes, and the yellow and light brown surrounded the graphite flakes are Ferrite.
Record of Microstructures

<table>
<thead>
<tr>
<th>Specimen No.: 18</th>
<th>Specimen name</th>
<th>Material</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ferrous Metal</td>
<td>White Cast Iron</td>
<td>As cast, etched</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
<th>Co</th>
<th>W</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.80-3.60</td>
<td>0.50-1.90</td>
<td>0.25-0.80</td>
<td>0.06-0.20</td>
<td>0.06-0.20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Similar steels:
- USA: AISI/SAE
- Germany: DIN 1695
- FRANCE: AFNOR NF A32-401
- RUSSIA: G-X300NiMo3Mg
- CHINA: FBO
- SWEDEN: DIN 1695
- JAPAN: AFNOR NF A32-401
- ITALY: DIN 1695
- INDIA: IS7925
- UK: BS 4844

Characteristics and applications:
Exhibits a white, crystalline fracture surface because fracture occurs along the iron carbide plates; it is the result of metastable solidification (Fe3C eutectic). Hard and brittle. Good wear resistant. Weldability is poor. Machinability is poor. If reheated above eutectoid interval, soaked and cooled through eutectic interval, malleable iron will be achieved. Alloying elements can be added to white iron to make alloy cast iron, e.g., Cr is added for wear resistant purpose.

Heat treatment guide:
Only stress relieving is recommended for white cast iron when high wear resistant is required. Stress relieving of white cast iron can be done by heating the parts to about 550-650°C, soaking time is 1 hour per 25 mm. of thickness and air cool. White cast iron can be hardened also to get martensite matrix but seldomly practice.

Manufacturing process of this specimen:
- Charge: Raw materials (pig iron, scraps, ferro-alloy material, and fluxes) are put in the induction furnace and poured into prepared sand mould. The raw materials added must be calculated and weighed before charging into the furnace to achieve the composition required.
Photo 63: 1000x, Same as in Photo 62, but in larger area, showing Pearlite, and Ledeburite.

- **Pearlite**
- **Cementite**
### Record of Microstructures

<table>
<thead>
<tr>
<th>Specimen No.: 19</th>
<th>Specimen name</th>
<th>Material</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ferrous Metal</td>
<td>Malleable iron (annealed white cast iron)</td>
<td>annealed</td>
</tr>
</tbody>
</table>

**Chemical composition**

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
<th>Co</th>
<th>W</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.20-2.90</td>
<td>0.90-1.90</td>
<td>0.15-1.20</td>
<td>0.02-0.20</td>
<td>0.02-0.20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>---------</td>
</tr>
</tbody>
</table>

**Similar steels**

- USA
- INTERNATIONAL
- FRANCE
- RUSSIA
- NETHERLANDS
- JAPAN
- ITALY
- INDIA
- UK

**Characteristics and applications:** Malleable iron is a type of cast iron that has most of carbon in the form of irregular shaped graphite nodules instead of flakes. Malleable iron is produced by first casting the casting as a white iron and then heat treating the white iron to convert the iron carbide into the irregularly shaped nodules of graphite. This form of graphite is called temper carbon because it is formed in the solid state during heat treatment. Malleable iron is good for making flanges, pipe fittings, valve parts for railroad, marine, etc.

**Heat treatment guide:**

1. First stage anneal of the casting and air cool, about 0.75% of combined carbon will remain in the matrix.
2. Reheat the casting at 885°C for 60 min. to re austenitize the matrix and homogenize the combined carbon; and then quench in heated (50-55°C) and agitated oil to form martensite with the hardness of about 555 to 627 HB. Then temper to the required hardness. And also malleable iron can be carburized, carbonitrided, and nitrided to add surface wear resistance.

### Manufacturing processes of this specimen

1. **Casting:** The raw materials were calculated, weighed and charged and melted in the induction furnace, then poured into the sand mould. After the solidification, the casting was taken out from the mould for the next process.
2. **Annealing:**
   - **Step 1:** Heating to 955°C, the temper carbon nucleus will be initiated.
   - **Step 2:** Holding at 955°C: this step is called first-stage graphitization (FSG), massive carbides are eliminated from the iron structure. The soaking time may be about at least 48 hours. Then the casting is rapidly cooled to 740°C prior to entering the second-stage graphitization.
   - **Step 3:** Slow cooling; the casting was slow cooled through the allotropic transformation range of the iron; this step is called second-stage graphitization (SSG), a completely ferritic matrix free of pearlite and carbide is obtained.

### Microstructures

**Photo.64:** 100x, Dark gray islands are tempered graphites. Purple and blue-green area are Ferrite.

**Photo.65:** 1000x, Same as in Photo.64, but in higher magnification. Dark gray islands are tempered graphite. The matrix is Ferrite.
Photo.66: 500x, Same as in Photo.65, but in larger area. Dark gray islands are tempered graphite. Purple and blue-green area are Ferrite.
**Characteristics and applications:**

Nodular cast iron can be called Ductile cast iron or spheroidal graphite (SG) cast iron, it is cast iron in which the graphite is present as tiny spheres (nodules). The eutectic graphite separates from the molten iron during solidification and grows as spheres due to the additives introduced into the molten iron before casting.

Some of the applications for nodular cast iron include: gears, high-fatigue strength application, high-impact application, automotive crankshafts, compressor crankshafts, joints, etc.

**Heat treatment guide:**

<table>
<thead>
<tr>
<th>Heat treatment</th>
<th>Description</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
<th>Austempering</th>
<th>Nitriding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
<td>510-565</td>
<td>870-900</td>
<td>845-925</td>
<td>425-600</td>
<td>845-925</td>
<td>850-870</td>
<td>1050-1100</td>
<td>550-650</td>
</tr>
<tr>
<td>Soaking time, min.</td>
<td>1 hr. / 25 mm. + 1 hr.</td>
<td>1 hr. / 25 mm. + 1 hr.</td>
<td>1 hr. / 25 mm. + 1 hr.</td>
<td>2 hrs min.</td>
<td>1 hr. / 25 mm. + 1 hr.</td>
<td>10 - 75 hrs.</td>
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</tr>
<tr>
<td>Quenching medium</td>
<td>air or nitrogen</td>
<td>furnace cool</td>
<td>oil or water</td>
<td>air or faster</td>
<td>oil or water</td>
<td>furnace cool</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>163-217 HB</td>
<td>160-180 HB</td>
<td>45-56 HRC</td>
<td>30 HRC - 80 HRC</td>
<td>45-58 HRC</td>
<td>550-650 HVC</td>
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</tr>
</tbody>
</table>

**Manufacturing process of this specimen:**

The charges (consist of pig iron, cast iron scraps, steel scraps, FeSi, FeMn, flux) were charged into induction furnace and melted into liquid metal, then the molten metal was discharged into the crucible and then poured into the sand mould. Molten metal will be solidified into solid (casting). The casting was cut, mounted, ground, and polished to show graphite shapes, sizes and distribution.

**Microstructures:**

Photo 67: 100x, Nodular cast iron, unetched, showing spheroidal graphites (dark brown particles).

Photo 68: 1000x, Same as in Photo 67, but in higher magnification. Dark gray island is spheroidal graphite.
Photo. 69: 200x, Round particles are spheroidal graphites. The matrix can not be revealed in unetched condition.
Characteristics and applications:
Nodular can be called Ductile cast iron or spheroidal graphite(SG) cast iron, it is cast iron in which the graphite is present as tiny spheres(nodules). The eutectic graphite separates from the molten iron during solidification and grows as spheres due to the additives introduced into the molten iron before casting.
Some of the applications for nodular cast iron include: gears, high-fatigue strength application, high-impact application, automotive crankshafts, compressor crankshafts, joints, etc.

Heat Descriptions Processes
<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Full hardening</th>
<th>Tempering</th>
<th>Austempering</th>
<th>Nitriding</th>
</tr>
</thead>
<tbody>
<tr>
<td>510-565</td>
<td>870-900</td>
<td>845-925</td>
<td>425-600</td>
<td>845-925</td>
<td>450-10</td>
<td>550-650</td>
</tr>
<tr>
<td>Soaking time, min.</td>
<td>1hr./25 mm.+1 hr.</td>
<td>1hr./25 mm.+1 hr.</td>
<td>2 hrs min.</td>
<td>1hr./25 mm.+1 hr.</td>
<td>10-75 hrs.</td>
<td></td>
</tr>
<tr>
<td>Quenching medium</td>
<td>air or nitrogen</td>
<td>furnace cool</td>
<td>oil or water</td>
<td>air or faster</td>
<td>oil or water</td>
<td>furnace cool</td>
</tr>
<tr>
<td>Hardness</td>
<td>163-217 HB</td>
<td>160-180 HB</td>
<td>45-56 HRC</td>
<td>30HRC-80HRB</td>
<td>45-58 HRC</td>
<td>550-650HV</td>
</tr>
</tbody>
</table>

Manufacturing process of this specimen:
The charges (consist of pig iron, cast iron scraps, steel scraps, FeSi, FeMn, flux) were charged into an induction furnace and melted into liquid metal, then the molten metal was discharged into the crucible and then poured into the sand mould. Molten metal will be solidified to solid(casting). The casting was cut, mounted, ground, and polished to show graphite and matrix.

Microstructures:
- Photo.70:100x, Nodular cast iron, etched, brown round particles are spheroidal graphites. The matrix are Ferrite/white, purple area, and Pearlite/brown islands.
- Photo.71:1000x, Same as in Photo.70, but in higher magnification. Gray area is graphite. Purple and blue-green area are Ferrite.
Photo.72: 500x, Same as in Photo.71, but in larger area. The microstructures consist of spheroidal graphites, Pearlite and Ferrite. Bull's eyes structure can be seen in this Photo. (Bull's structure consists of graphit nodule in the center surrounded with Ferrite, and the outmost area is Pearlite. It looks like Bull's eyes.)
### Chemical composition

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Specimen name</th>
<th>Material</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Ferrous Metal</td>
<td>Bainitic Ductile Iron(BDI)</td>
<td>as cast</td>
</tr>
</tbody>
</table>

Chemical composition:
- C: 3.50%
- Si: 2.50%
- Mn: 0.90%
- P: 0.050%
- S: 0.040%
- Cr: -
- Mo: 0.25%
- Ni: 3.00%
- V: -
- Ti: -
- Co: -
- W: -
- Others: -

### Characteristics and applications:

Bainitic Ductile Iron (BDI) is a high strength and wear resistant alloy cast iron. Microstructure of BDI consists of graphite nodules and bainite as the matrix. BDI obtained through alloying during melting to produce bainite matrix which is hard and good wear resistant. Bainite matrix in BDI obtained in as cast condition without any heat treatment. The applications of BDI are: gear, crank shafts, etc.

### Heat treatment:

BDI may be tempered to adjust the hardness. The tempering temperature depends on the hardness required. The other heat treatment processes may not be required because the casting has been already hardened by alloying.

### Manufacturing process of this specimen

1. **Charge**
2. **Melting**
3. **Pouring**
4. **Casting**

### Microstructures

- **Photo.73**: 100x, Bainitic Ductile Iron (BDI), etched, showing Bainite matrix and spheroidal graphite.
- **Photo.74**: 1000x, Same as in Photo.73, but in higher magnification. Brown round area is spheroidal graphite surrounded with Bainite (purple, orange, blue-green, and brown area).
Photo 75: 1000x, Same as in Photo 74, but in larger area. The microstructures consist of spheroidal graphites, and Bainite matrix. Some ferrite remained beside graphite.
### Characteristics and applications:

This grade of cast iron is in the group of high alloy white irons which are primarily used for abrasion-resistant applications and are readily cast in the shapes needed in the machinery used for crushing, grinding, and general handling of abrasive materials. The eutectic carbides in the microstructures provided the high hardness needed for crushing and grinding other materials. All high-alloy white irons contain chromium to prevent graphite formation and provide the stability of carbide phase.

### Manufacturing process of this specimen

1. **Charge**
2. **Melting**
3. **Pouring**
4. **Casting**
5. **Full hardening**

**Processes:** The raw material (pig iron, scraps, ferro-alloys, etc.) were charged into the induction furnace for melting. Then the liquid metal was discharged and poured into the sand mould. After the solidification, the casting was taken out of the mould and heated to 1010°C and air cooled and tempered at 250°C.

### Microstructures

**Photo.76:** 100x, Wear resistant cast iron, etched. The structures are chromium carbides.

**Photo.77:** 1000x, Same as in Photo.76, but in higher magnification.
Photo 78: 500x, Same as in Photo 77, but in larger area. The structures are chromium carbides.
Specimen No.: 24

**Chemical composition**
- C: 1.40-1.60%
- Si: 0.60%
- Mn: 0.60%
- P: 0.03%
- S: 0.03%
- Cr: 11.00-13.00%
- Mo: 0.70-1.20%
- Ni: 1.10 max
- V: -
- Ti: -
- Co: -
- W: -
- Others: -

**Similar steels**
- USA: D2
- GERMANY: D2
- FRANCE: Z160CDV12
- CHINA: 3-2Cr12MoV
- SWEDEN: GB 1299
- JAPAN: SIS14
- ITALY: JISG4404
- INDIA: UNI2955
- UK: IS 3749

**Characteristics and applications:** Most available and most popular of the D series tool steels. Deep hardening, with low distortion and high safety in weldability. Resistant to softening and medium resistant to decarburization. Readily nitrided. D2 steel is air hardening and attain full hardness when cooled in still air. D2 steel contain massive amount of carbides, which make it susceptible to edge brittleness. Typical applications of D2 steel include long run dies for blanking, forming, thread rolling, deep drawing, slitter knives, etc.

**Heat treatment guide**
- **Temperature, °C**
  - Annealing: 870-900, 675-705
  - Stress relieving: 815-900
  - Hardening: 815; Aus: 980-1025
  - Tempering: 205-540
  - Nitriding: 500
- **Soaking time, min.**
  - Annealing: 60 min./inch of thickness
  - Stress relieving: 15 min.(small); 45 min.(large)
  - Hardening: 2 hrs min.
- **Quenching medium**
  - Annealing: furnace cool, air
  - Stress relieving: air, or nitrogen gas
  - Hardening: air, furnace cool
- **Hardness**
  - Annealing: 62 to 64 HRC
  - Stress relieving: 61-750 HV
  - Hardening: >750 HV

**Final heat treatment process of this specimen**
- **Temperature, °C**
  - Preheat: 815
  - Furnace cool: 90
  - Annealing: 880
- **Process:** The specimen is heated to 880°C for 90 min., then cool down slowly in the furnace, austenite will transform to ferrite and pearlite. The steel will be softened, better machinability, better cold workability, and improve dimensional stability, etc.

**Microstructures**
- Photo.79: 100x, AISI D2 Tool steel, annealed. Microstructures consist of Ferrite matrix and Carbides.
- Photo.80: 1000x, Same as in Photo.79, but in higher magnification. Ferrite matrix is colored green and brown. Carbides remained bright particles.
Photo 81: 1000x, Same as in Photo 80, but in larger area, showing the distribution of Carbides in Ferrite matrix.
### Characteristics and applications:
Most available and most popular of the D series tool steels. Deep hardening, with low distortion and high safety in weldability. Resistant to softening and medium resistant to decarburization. Readily nitrided. D2 steel is air hardening and attain full hardness when cooled in still air. D2 steel contain massive amount of carbides, which make it susceptible to edge brittleness. Typical applications of D2 steel include long run dies for blanking, forming, thread rolling, deep drawing, slitter knives, etc.

### Heat treatment guide

**Temperature, °C**
- Annealing: 870 - 900
- Stress relieving: 675-705
- Tempering: 205-540
- Nitriding: 500

**Soaking time, min.**
- Normalizing: 2 hrs
- Annealing: 10-75 hrs.
- Stress relieving: 15 min.(small); 45 min.(large)
- Tempering: 2 hrs min.
- Nitriding: 10-75 hrs.

**Quenching medium**
- Normalizing: furnace cool
- Annealing: air
- Stress relieving: air or nitrogen gas
- Tempering: air
- Nitriding: furnace cool

**Hardness**
- Final: 217-255 HB
- 62 to 64 HRC
- 61-54 HRC

### Final heat treatment process of this specimen
- **Process:** The specimen is heated to 1025°C for 90 min., the steel microstructures will transform to austenite, then quench in nitrogen gas(in vacuum furnace), austenite will transform to martensite and then temper immediately at 520°C after the specimen has cooled to about 50°C, Double temper.

### Microstructures

Photo.82:100x. AISI D2 Tool steel, quenched and tempered. Microstructures consist of Martensite and Carbides.

Photo.83:1000x. Same as in Photo.82, but in higher magnification. Martensite tinted various colors. Carbides remained bright particles.
Photo.84: 1000x. Same as in Photo.83, but in larger area. The matrix is Martensite tinted various colors, and bright particles are carbides.
Record of Microstructures

Specimen No.: 26
Ferrous Metal
Mould tool steel (AISI P20)

Specimen name
Material
Condition

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
<th>Co</th>
<th>W</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.10</td>
<td>0.10-0.40</td>
<td>0.10-0.40</td>
<td>0.025 max</td>
<td>0.025 max</td>
<td>0.75-1.25</td>
<td>0.15-0.40</td>
<td>0.10-0.50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Similar steels

<table>
<thead>
<tr>
<th>USA</th>
<th>GERMANY</th>
<th>FRANCE</th>
<th>SWEDEN</th>
<th>JAPAN</th>
<th>RUSSIA</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI/SAE</td>
<td>ASTM A681</td>
<td>DIN</td>
<td>KRUPP</td>
<td>AFNOR NF A35-590</td>
<td>SS14</td>
<td>ASSAB</td>
</tr>
<tr>
<td>P20</td>
<td>P20</td>
<td>1.2311</td>
<td>2311</td>
<td>35CM7D</td>
<td>USA P20</td>
<td>718Supreme</td>
</tr>
</tbody>
</table>

Characteristics and applications:

Mold steel AISI P20 normally is supplied heat treated to 30-36 HRC, a condition in which it can be machined readily into large, intricate dies and molds. Because this steel is prehardened, no subsequent high temperature heat treatment is required, and distortion and size changes are avoided. However, when used for plastic mold, type P20 is sometimes carburized and hardened after the impression has been machined. Most application is for plastic mold making.

Heat treatment guide

<table>
<thead>
<tr>
<th>Description</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Stress relieving</th>
<th>Hardening</th>
<th>Tempering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
<td>900</td>
<td>760-790</td>
<td>650-675</td>
<td>Carburize:920, Harden: 815-870</td>
<td>Carburized mold:175-230</td>
<td></td>
</tr>
<tr>
<td>Soaking time, min.</td>
<td>60 min./inch of thickness</td>
<td>60 min./inch of thickness</td>
<td>60 min./inch of thickness</td>
<td>Carburize:to case depth; Harden:15 min</td>
<td>2 hrs min.</td>
<td></td>
</tr>
<tr>
<td>Quenching medium</td>
<td>air</td>
<td>furnace cool</td>
<td>air</td>
<td>oil</td>
<td>air</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>149-179 HB</td>
<td>149-212 HB</td>
<td>-</td>
<td>60 to 64 HRC</td>
<td>62- 58 HRC</td>
<td></td>
</tr>
</tbody>
</table>

Final heat treatment process of this specimen

<table>
<thead>
<tr>
<th>°C</th>
<th>780</th>
<th>furnace cool</th>
</tr>
</thead>
<tbody>
<tr>
<td>preheat</td>
<td>815</td>
<td></td>
</tr>
<tr>
<td>30 min.</td>
<td>60 min.</td>
<td></td>
</tr>
</tbody>
</table>

Microstructures

Photo.85:100x, AISI P20 Mold Tool steel, annealed. Microstructures consist of Ferrite and Carbides. Black dots are porosities.

Photo.86:1000x, Same as in Photo.85, but in higher magnification. Blue-green area are Ferrite. Bright particles are Carbides.
Photo.87:1000x, Same as in Photo.86, but in larger area.
### Characteristics and applications:

Mold steel AISI P20 normally is supplied heat treated to 30-36 HRC, a condition in which it can be machined readily into large, intricate dies and molds. Because this steel is prehardened, no subsequent high temperature heat treatment is required, and distortion and size changes are avoided. However, when used for plastic mold, type P20 is sometimes carburized and hardened after the impression has been machined. Most application is for plastic mold making.

**Heat treatment guide**

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Processes</th>
<th>Normalizing</th>
<th>Annealing</th>
<th>Stress relieving</th>
<th>Hardening</th>
<th>Tempering</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>60 min./inch of thickness</td>
<td>air</td>
<td>60 min./inch of thickness</td>
<td>Carburize:920, Harden: 815-870</td>
<td>Carburized mold:175-230</td>
<td></td>
</tr>
<tr>
<td>149-179 HB</td>
<td>15</td>
<td>300</td>
<td>300</td>
<td>60 to 64 HRC</td>
<td>62- 58 HRC</td>
<td></td>
</tr>
</tbody>
</table>

**Final heat treatment process of this specimen**

- **Process:** The specimen is heated to 850°C for 15 min., the steel microstructures will transform to austenite, then quench in oil, austenite will transform to martensite. Then temper at 300°C for 120 min.
- **Microstructures:**

  - **Photo.88:** 100x, Microstructures consist of tempered Martensite and some inclusions.
  - **Photo.89:** 1000x, Same as in Photo.88, but in higher magnification. Martensite is clearly seen in brown and gray.
Photo.90: 1000x. Same as in Photo.88, but in larger area. The structure is tempered martensite.
### Chemical Composition

<table>
<thead>
<tr>
<th>Chemical</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
<th>Co</th>
<th>W</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen No.: 28</td>
<td>0.95-1.05</td>
<td>0.20-0.45</td>
<td>0.15-0.40</td>
<td>0.03 max</td>
<td>0.003 max</td>
<td>3.75-4.5</td>
<td>4.50-6.75</td>
<td>0.30 max</td>
<td>2.25-2.75</td>
<td>-</td>
<td>-</td>
<td>5.00-6.75</td>
<td>-</td>
</tr>
</tbody>
</table>

### Similar Steels

<table>
<thead>
<tr>
<th>Similar Steels</th>
<th>USA</th>
<th>GERMANY</th>
<th>FRANCE</th>
<th>SWEDEN</th>
<th>JAPAN</th>
<th>RUSSIA</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2</td>
<td>M2 high C</td>
<td>1.3345</td>
<td>5600</td>
<td>4301 6-5-2</td>
<td>2722</td>
<td>ASC-41</td>
<td>SKH 51</td>
</tr>
</tbody>
</table>

### Characteristics and Applications

M2 is the most widely used high speed steel suitable for a multitude of applications and available with several carbon contents. M2 is very high in resistance to wear and to softening at elevated temperature. It rates low in toughness, but using a lower austenitizing temperature with the resulting slightly lower hardness improves its impact resistance. Mostly M2 is used for various cutting tools e.g. hack saw blades, drills, taps, cutters, single point cutting tools, etc.

### Heat Treatment Guide

- **Temperature, °C**:
  - Descriptions: 870-900, 650-675
  - Normalizing: Do not normalize
  - Annealing: 870-900
  - Stress relieving: 650-675
  - Hardening: Double preheat: 650/850, Austenitize: 1190-1230
  - Tempering: 540-595
- **Soaking time, min.**:
  - 60 min./inch of thickness
  - 60 min./inch of thickness
  - 15
- **Quenching medium**:
  - Furnace cool
  - Air
  - Nitrogen quench in vacuum furnace
  - Air
- **Hardness**:
  - 212-241 HB
  - 64-66 HRC
  - 65-60
  - 450
  - 1190

### Final Heat Treatment Process

- **Preheat**: 650°C, 30 min.
- **Austenitize**: 1190°C, 15 min.
- **Nitrogen quench in vacuum furnace**
- **Tempering**: 64-66 HRC

### Microstructures

**Photo.91: 100x, High speed steel, quenched and tempered. Microstructures consist of Martensite and Carbides.**

**Photo.92: 1000x, Same as in Photo. 91, but in higher magnification. Brown and dark gray background are Martensite. Light brown particles are Carbides.**
Photo.93: 1000x. Same as in Photo. 92, but in larger area. Microstructures consist of Martensite (brown and dark gray needle structures), and carbides (light brown round and elongated particles).
Table:

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
<th>Cu</th>
<th>W</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen No.: 29</td>
<td>1.268</td>
<td>0.525</td>
<td>13.38</td>
<td>0.042</td>
<td>0.004</td>
<td>2.105</td>
<td>0.094</td>
<td>0.074</td>
<td>0.023</td>
<td>0.029</td>
<td>0.368</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Similar steels:
- USA: ASTM A128
- AUSTRALIA: AS 2074
- GERMANY: DIN 3160
- ITALY: G5131
- JAPAN: M5131
- MEXICO: MNC 720E
- ROMANIA: STAS 3718
- SPAIN: UNE 36253
- UK: BS 3100

Characteristics and applications:
The original austenitic manganese steel, containing about 1.2%C and 12%Mn, was invented by Sir Robert Hadfield in 1882. It combined high toughness and ductility with high-hardening capacity and excellent resistance to wear. It is still used extensively, with composition and heat treatment modification, primarily in the fields of earthmoving, mining, quarrying, oil well drilling, railroading, and in the manufacture of cement and clay products. Examples: rock crusher, bucket, wear plate, etc.

Manufacturing process of this specimen:
The charges (consist of pig iron, cast iron scraps, steel scraps, FeSi, FeMn, flux) were charged into an induction furnace and melted into liquid metal. Fe-Mn was added during the melting process. The liquid metal was discharged into the crucible and then poured into the sand mold. The liquid metal will solidify as the casting then cut, mounted, ground, polished, and etched for the examination.

Microstructures:
- Photo. 94: 50x, High-manganese steel casting, as cast. Microstructure are Austenite. White particles along grain boundaries and in the Austenite grains are Carbides.
- Photo. 95: 1000x, Same as in Photo. 94, but in higher magnification. Austenite grains are tinted various colors. Carbides along grain boundaries are colored light purple.
Photo. 96:200x, Same as in Photo. 95, but in larger area. Austenite grains are tinted various colors. Carbides are shown along grain boundaries and in Austenite grains.
Characteristics and applications: The original austenitic manganese steel, containing about 1.2%C and 12%Mn, was invented by Sir Robert Hadfield in 1882. It combined high toughness and ductility with high-hardening capacity and excellent resistance to wear. It is still used extensively, with composition and heat treatment modification, primarily in the fields of earthmoving, mining, quarrying, oil well drilling, railroad, and in the manufacture of cement and clay products. Examples: rock crusher, bucket, wear plate, etc.

Heat treatment guide: Heat treatment strengthens austenitic manganese steel so that it can be used safely and reliably in a variety of engineering applications. Solution annealing and quenching are the standard processes.

Manufacturing process of this specimen:

- The raw material (pig iron, scraps, ferro alloy, etc.) were charged into the induction furnace for melting.
- Then the liquid metal was discharged and poured into the sand mould.
- After the solidification, the casting was taken out of the mold and heated to 1050°C and quenched in water.

Microstructures:

- Photo.97: 50x, High Manganese Steel casting, annealed. Microstructures are Austenite. The purple area shows the trace of dendrite.

Specimen name: High manganese steel
Material: Solution annealed
Photo 99: 200x, Same as in Photo 98, but in larger area. The microstructures are Austenite. The grain boundaries are thinner and less carbide after annealing.