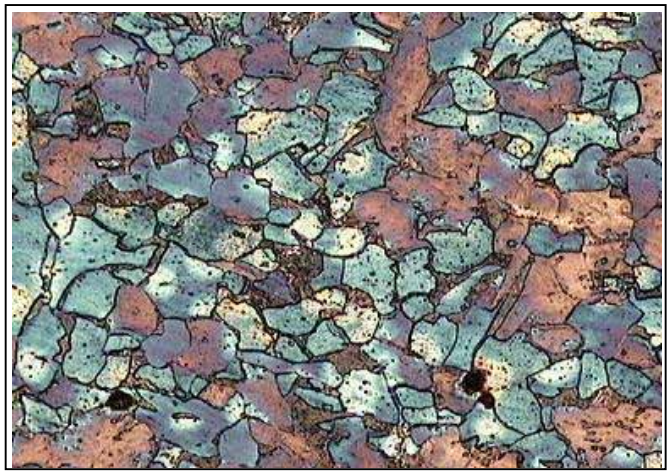
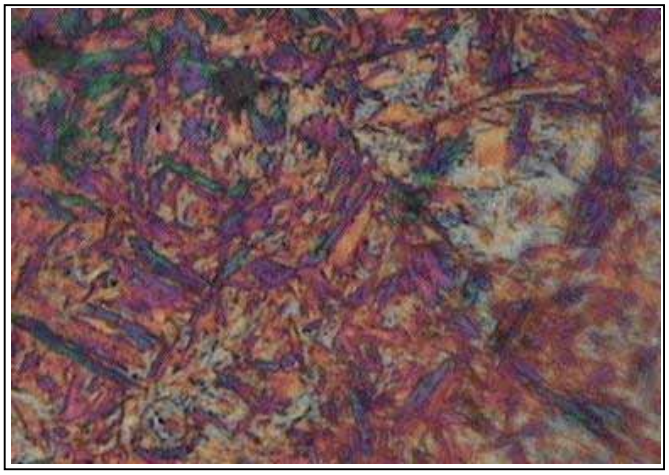
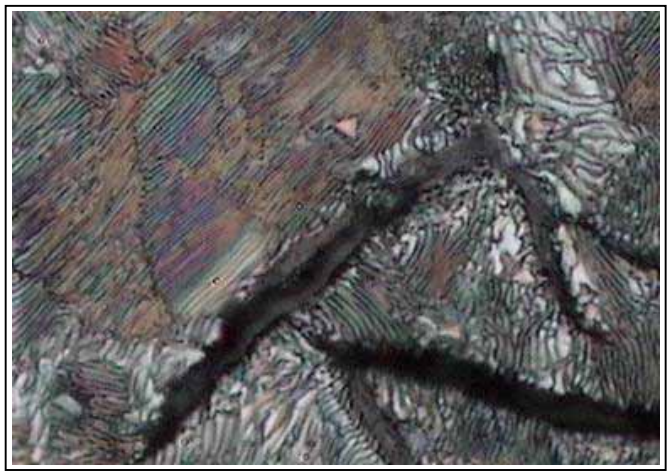
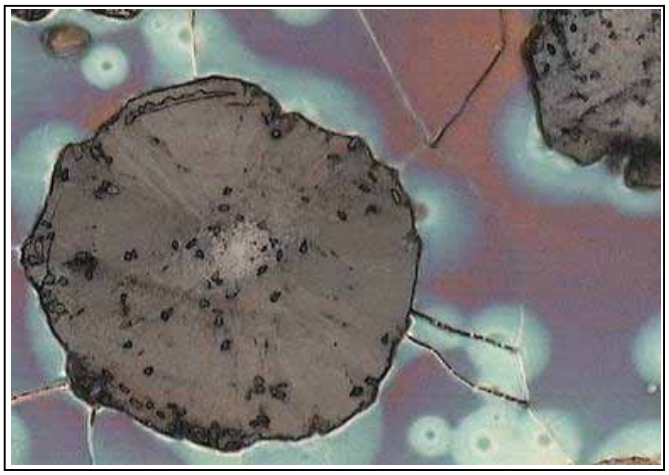
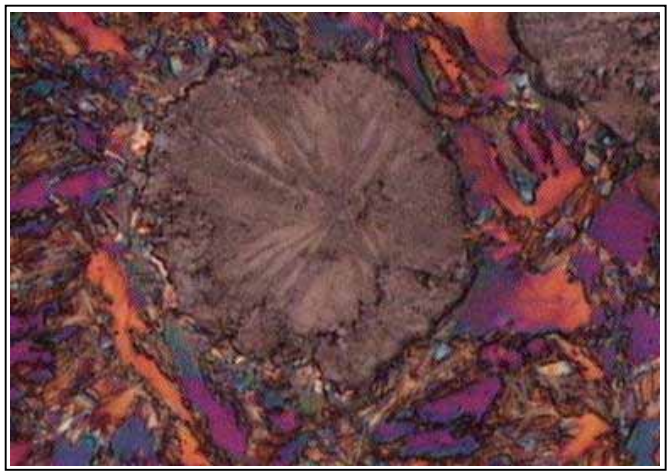
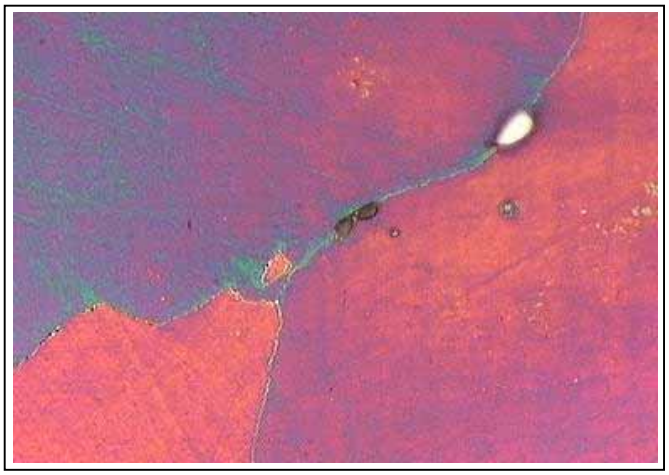
Metal specimen set
for
Metallurgical Study

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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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Contents

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.
3. Good conduction of heat and electricity.
4. High malleablity(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 devided into two classes: **Non-ferrous metals** and **Ferrous metals** which are also devided 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.

General Enginnering Materials

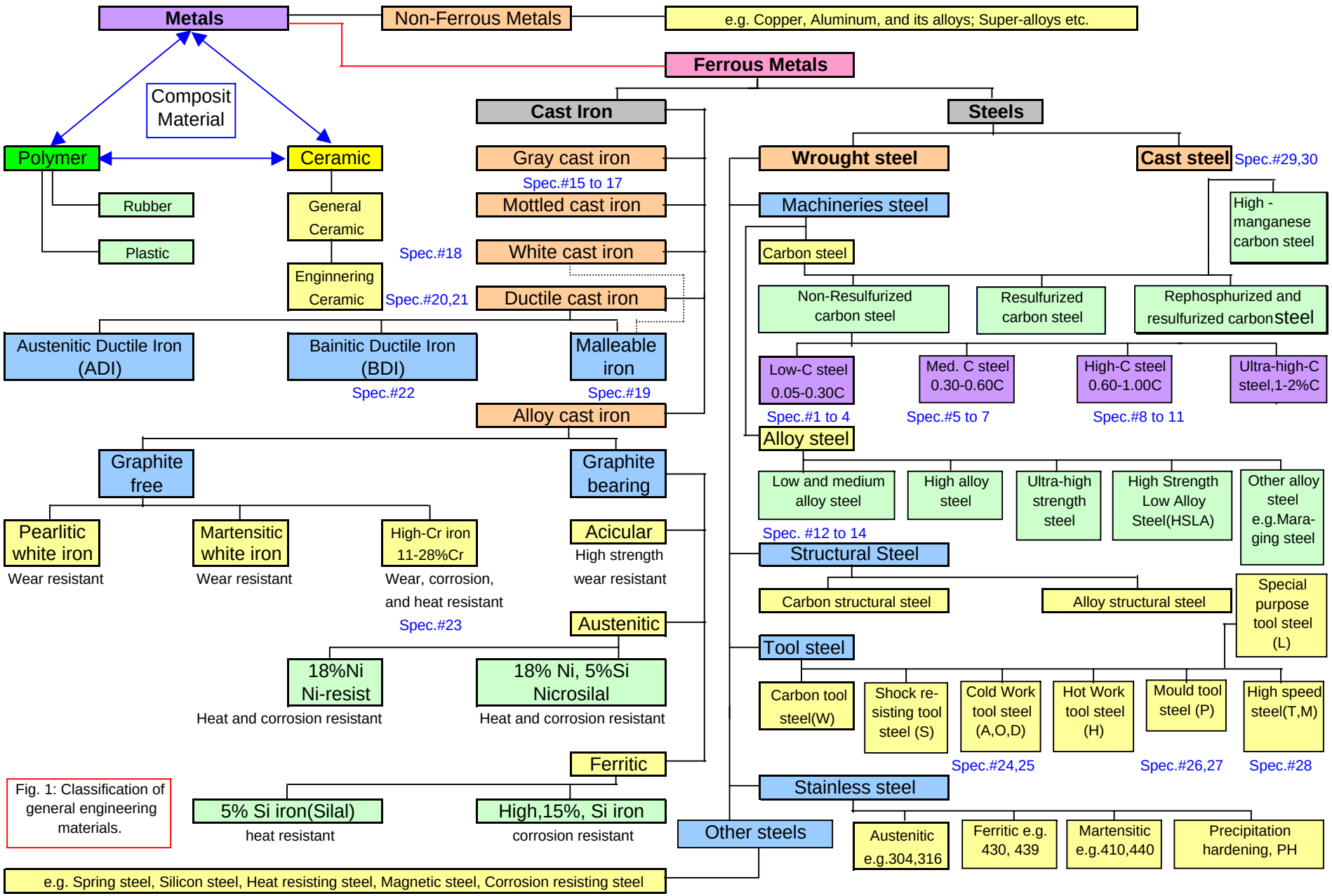
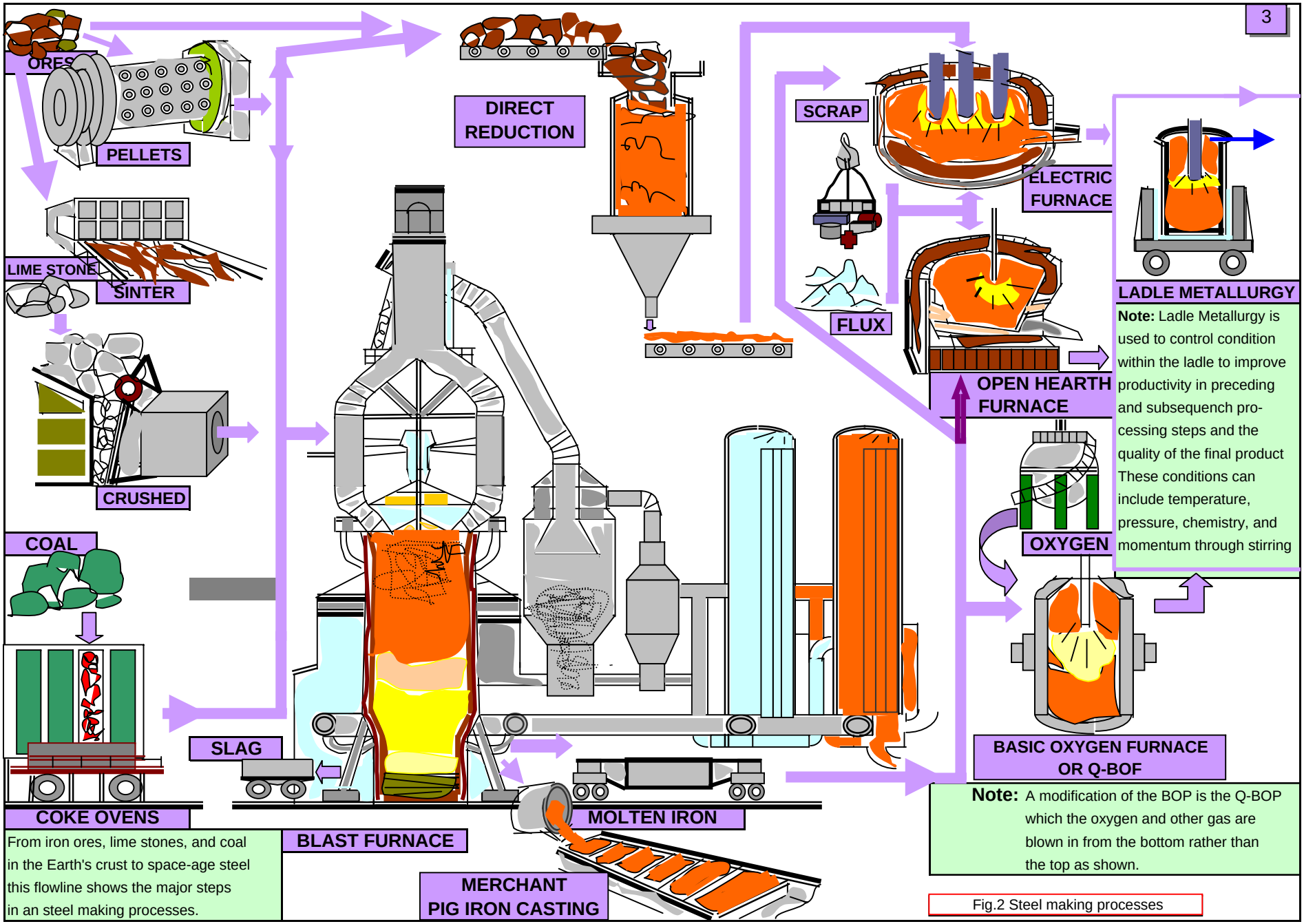


Fig. 1: Classification of general engineering materials.



From iron ores, lime stones, and coal in the Earth's crust to space-age steel this flowline shows the major steps in an steel making processes.

Note: Ladle Metallurgy is used to control condition within the ladle to improve productivity in preceding and subsequench 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.

Fig.2 Steel making processes

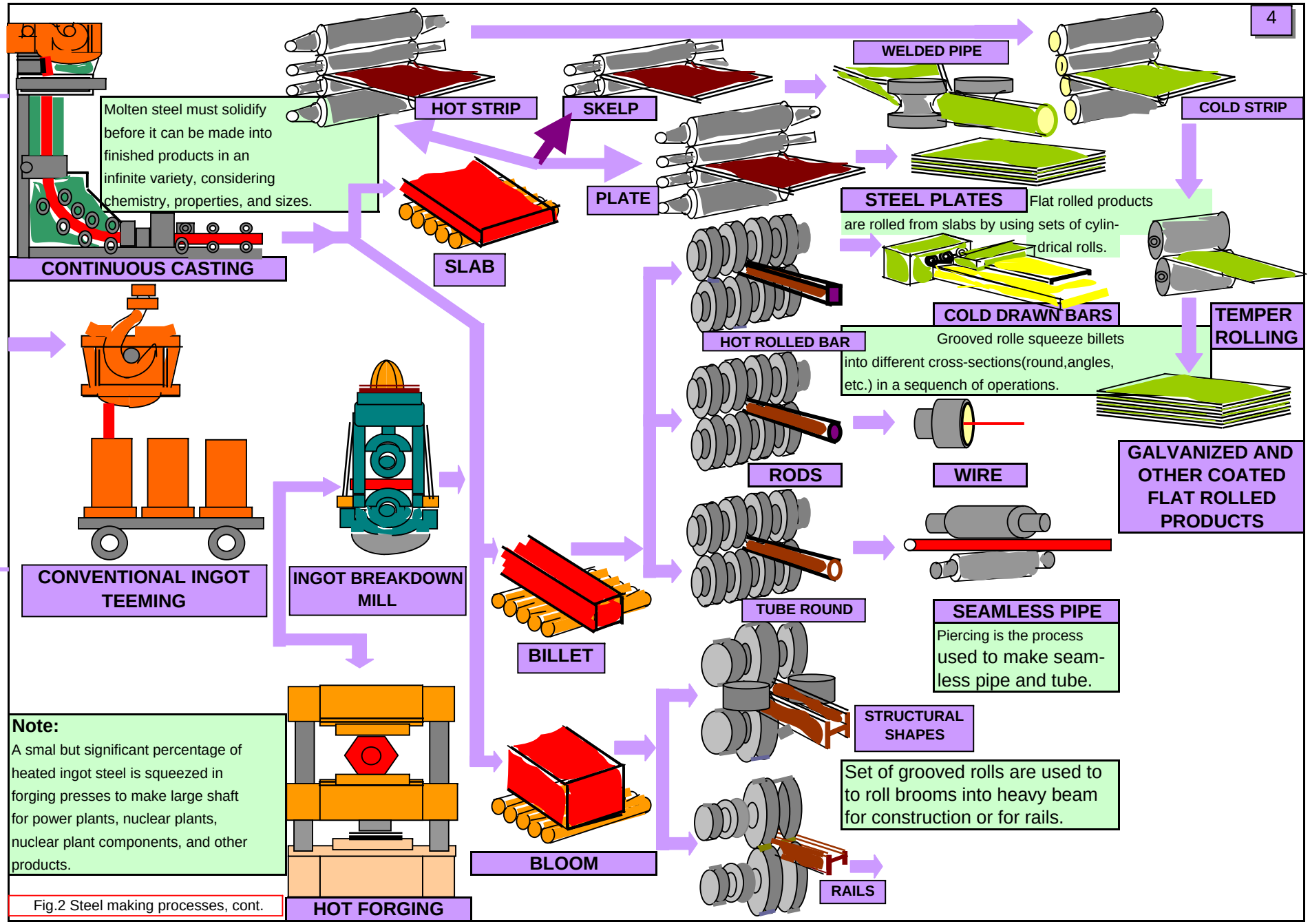


Fig.2 Steel making processes, cont.

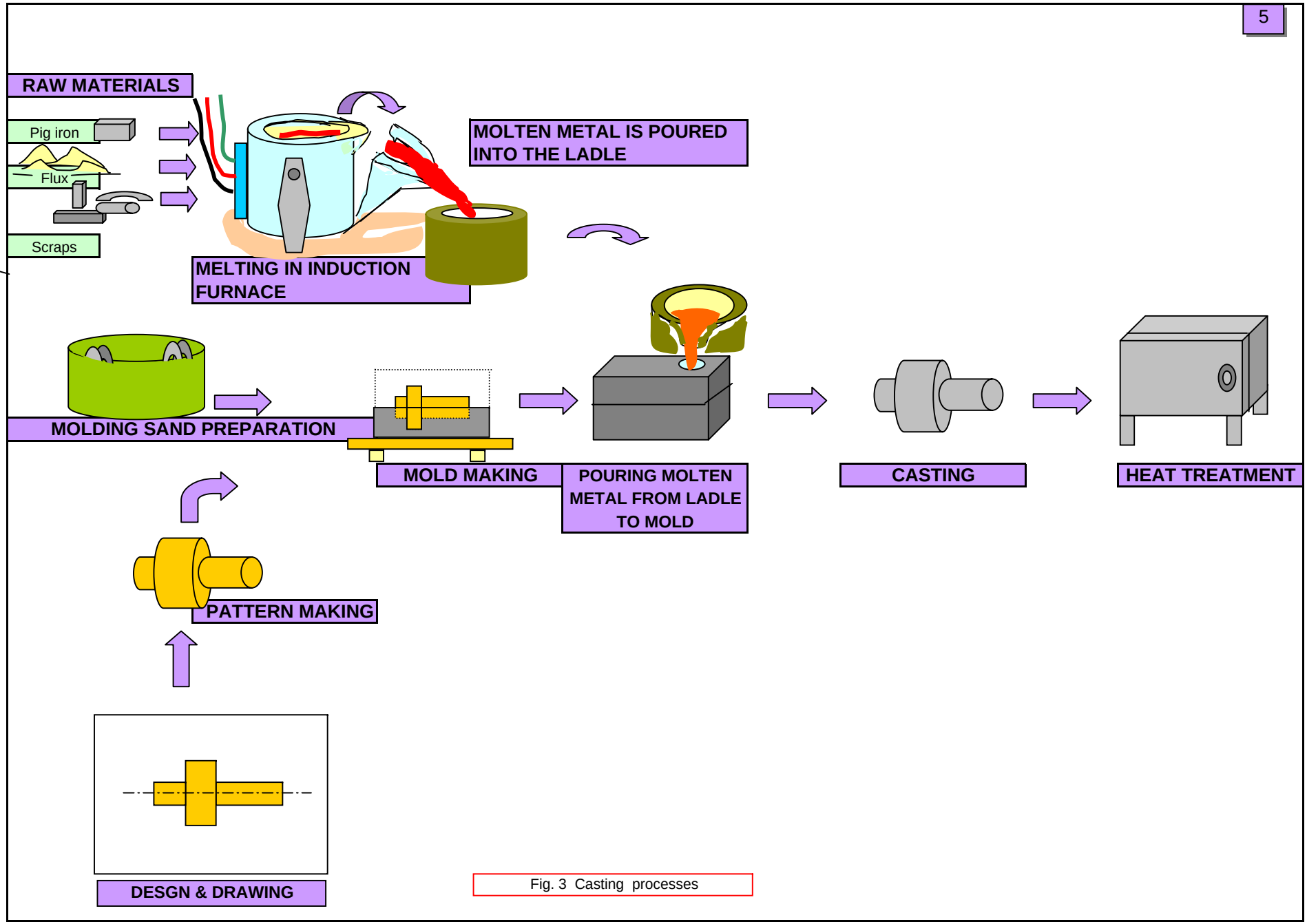
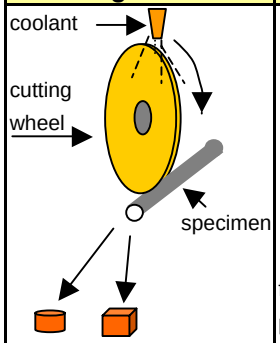


Fig. 3 Casting processes

Specimen preparation

1.Cutting



1.Equipment:

Lab cut-off machine

2.Cut-off wheel:

Resin bonded, both soft type(for hard specimen) and hard type(for soft specimen)

3.Coolant:

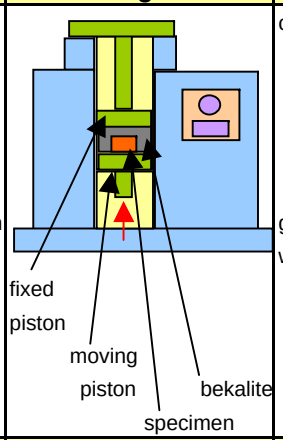
Water mixed with cooling medium and anti-bacteria solution.

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.

2.Mounting



1.Equipment:

Hot mounting machine

2.Resin type:

Phenolic resin(Bekelite) or Acrylic resin(transpa-lent type)

3.Temperature:

170-180^{0}C

4.Time:

8-12 min.

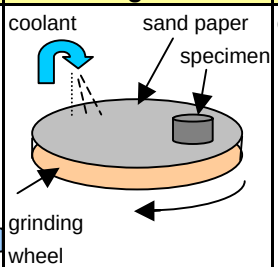
5.Coolant:

Water

Note:

The mounted specimen must be marked carefully to avoid confusing.

3.Grinding



1.Equipment:

Grinding machine

2.Grinding medium:

Water proof sand paper grit No.240,400,800,1200, and 2400

3.Coolant:

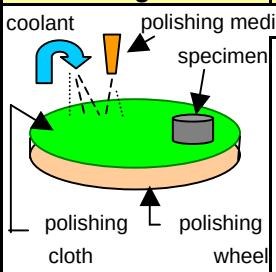
Water

Note:

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.

4.Polishing



1.Equipment:

Polishing machine

2.Polishing medium:

Polishing cloth and water suspended Alumina powder, 0.3 micron

3.Coolant:

Water

Note:

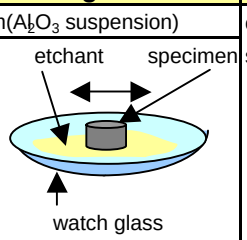
Before polishing, the specimen and hands must be clean.

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.

5.Etching



(Keep the specimen moving during etching)

1.Equipment:

Watch glass

2. Quenchant:

2.1 Reagent 7a.

2.2 Nital 3 %

3.Etching time:

15-30 seconds

4.Cleaning:

After etching, the specimen must be rinsed with flowing water and washed with alcohol and immediately blown with hot air.

Note:

1. Nital 3%:

Nitric acid(HNO_3): 3 cc

Alcohol: 97 cc

2. Reagent 7a:

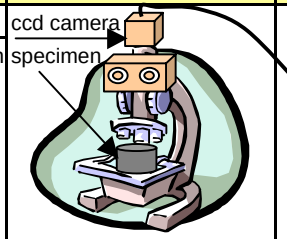
3 g potassium metabi-sulfite

1 g sulfamic acid

100 ml. Distilled water

(Reagent 7a is for color etcch)

6.Examination



metallurgical microscope

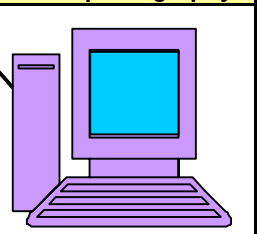
1.Equipment:

Metallurgical microscope, CCD camera, and specimen leveller.

2.The magnification:

50x,100x, 200x, 500x. and 1000x.

7.Micro-photography



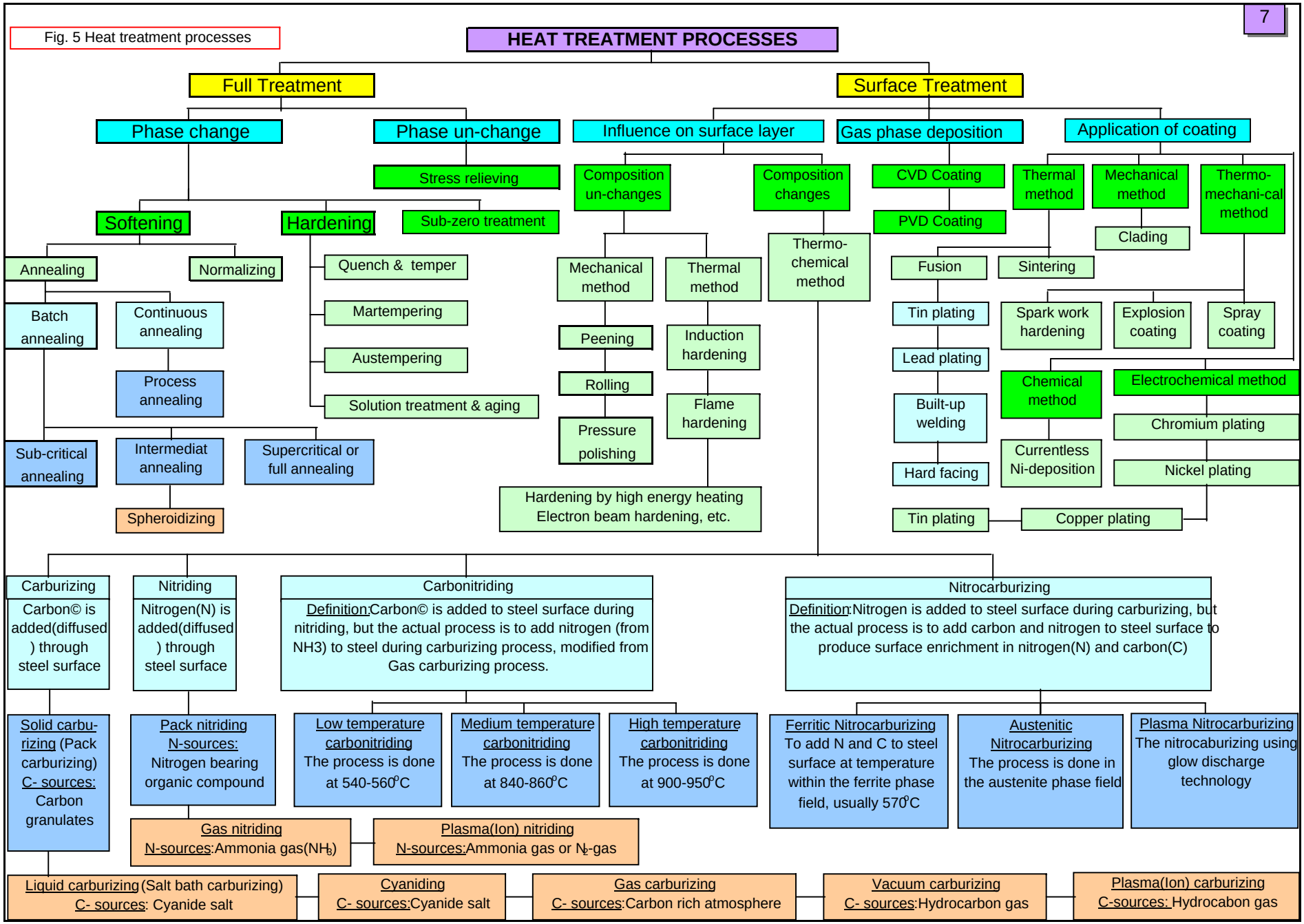
computer set and printer

1.Equipment:

Computer, printer.

Fig. 4 Specimen preparation

Fig. 5 Heat treatment processes



Record of Microstructures

Specimen No.: 1	Specimen name	Material	Condition
	Ferrous Metal	Low Carbon Steel	Annealed

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Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.18-0.23	0.15-0.35	0.30-0.60	0.04 max	0.04max	-	-	-	-	-	-	-	-

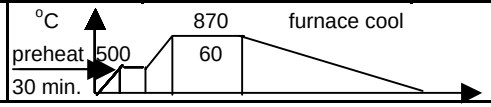
Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	GOST1050	GB 699	SS14	JIS	UNI5598	AS1442	BS
	1020	A29:1020	1.0402	-	CC20	20	20	1450	S20C	3CD20	CS1020	BS970:040A20

Characteristics: Most wildly used of several grade s containing about 0,20%carbon. Available in a variety of product forms. Excellent forgability and weldability. No preheating and post heating required before or after welding. Machinability is notably poor. Wildy 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	Descriptions / Processes	Normalizing	Through hardening	Carburizing	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	925	Because of low carbon	870-955	200-250	850-870	200-250	Nitriding is
	Soaking time, min.	1/2hr./25 mm.+1 hr.	and no alloying element	depend on case depth.	2 hrs min.	depend on case depth.	2 hrs min.	not recom-
	Quenching medium	air or nitrogen	Through hardening is not	oil	air	oil	air	mended.
	Hardness	120-130 HB	advisable.	60-62 HRC	55-60 HRC	60-62 HRC	55-60 HRC	

Final heat treatment process of this specimen



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 The steel will be softened,better machinability,better cold workability,and improve dimensional stability,etc

Microstructures

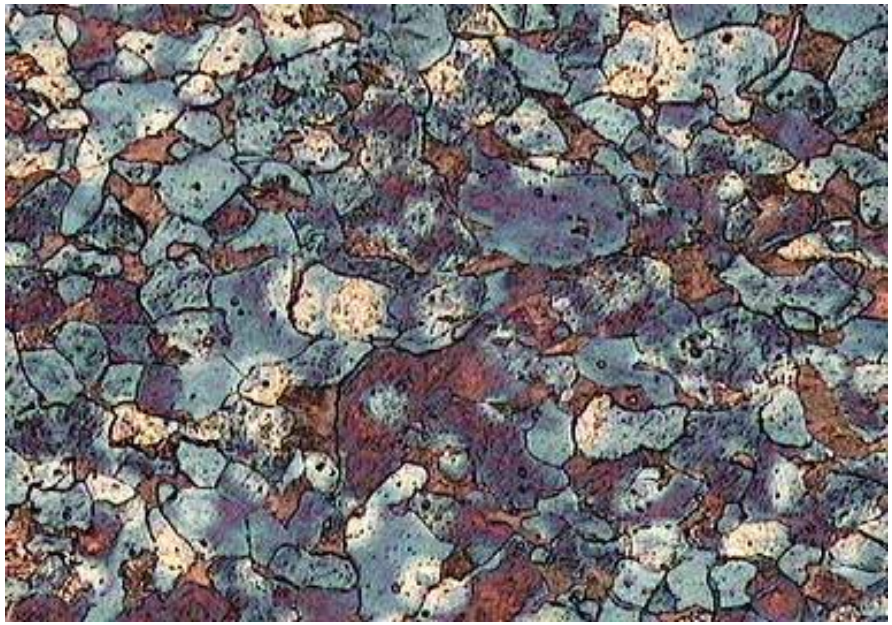


Photo.1: 200x,Microstructures consist of Ferrite(yellow, blue, and purple), and Pearlite (brown), small black dots are inclusions remain in steel.

200x，该显微结构包含铁素体（黄、蓝和紫色）及珠光体（棕色）， 小黑点是残留在铁中的夹杂物。

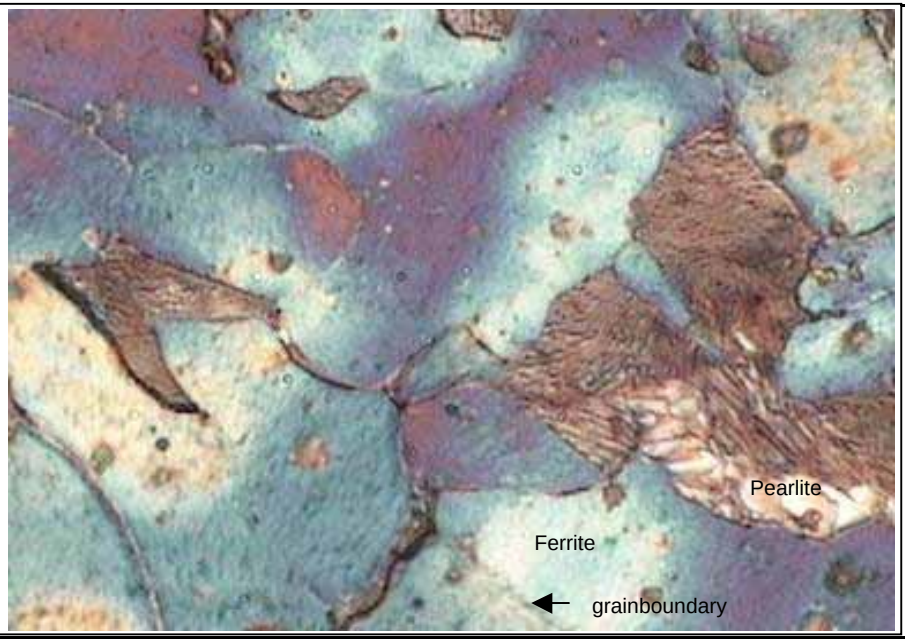


Photo.2. 1000x, same as in Photo. 1 but higher magnification. Brown area can be clearly

Ferrite: 铁素体; Pearlite: 珠光体; grainboundary: 晶粒间界

1000x，与图1相同，但放大倍数更高。棕色区域清晰可见珠光体中的渗碳体及铁素体。晶粒间界也清晰可见。

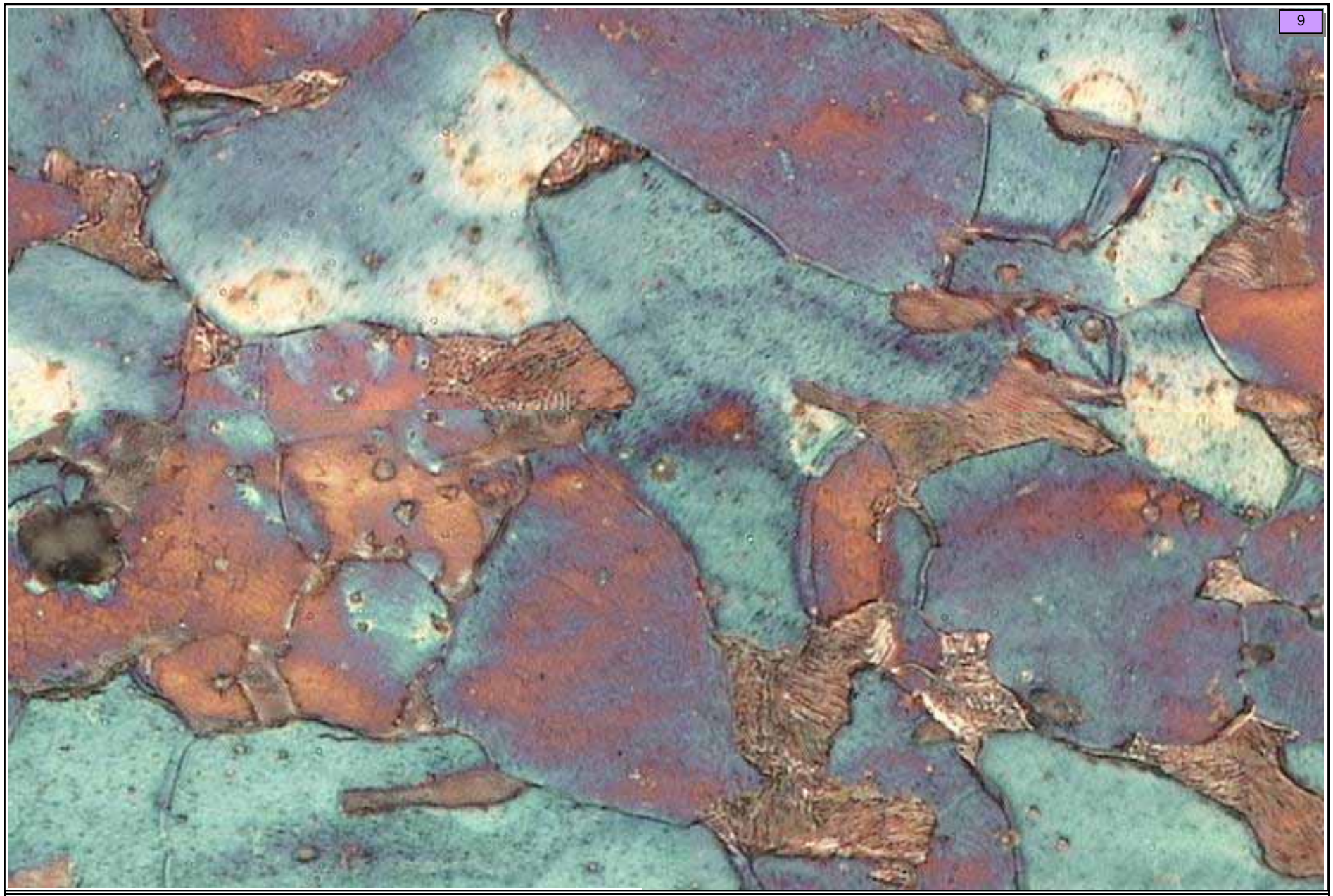


Photo.3: 1000x, Same as in Photo.1,2 but in large area. The microstructures consist of Ferrite(blue, green, purple, yellow) and Pearlite(brown area with Cementite strips on Feerite).

1000x,与图1、2相同，但面积更大。该显微结构包含铁素体（蓝、绿、紫和黄色）及珠光体（棕色区域为铁素体上的渗碳体带）。

Record of Microstructures

Specimen No.: 2	Specimen name	Material	Condition
	Ferrous Metal	Low Carbon Steel	Carburized

Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.18-0.23	0.15-0.35	0.30-0.60	0.04 max	0.04max	-	-	-	-	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	GOST1050	GB 699	SS14	JIS	UNI5598	AS1442	BS
	1020	A29:1020	1.0402	-	CC20	20	20	1450	S20C	3CD20	CS1020	BS970:040A20

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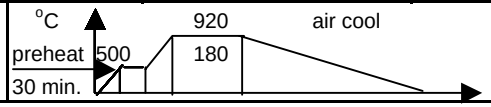
Applications: Parts for case hardened condition where core strength is not critical, and shaft for large section that are not highly stressed, case hardened gears pins and chain.

Heat treatment guide	Descriptions \ Processes	Normalizing	Through hardening	Carburizing	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	925	Because of low carbon and no alloying element Through hardening is not advisable.	870-955	200-250	850-870	200-250	Nitriding is not recom-mended.
	Soaking time, min.	1/2hr./25 mm.+1 hr.		depend on case depth.	2 hrs min.	depend on case depth.	2 hrs min.	
	Quenching medium	air or nitrogen		oil	air	oil	air	
	Hardness	120-130 HB		60-62 HRC	55-60 HRC	60-62 HRC	55-60 HRC	

Final heat treatment process of this specimen



Process: The specimen is heated to 920°C for180 min.in atmosphere controlled furnace with carbon potential o.9%. Carbon atom will diffuse into the specimen surface and combind with Fe to form Fe_3C or cementite in surface area, so pearlite increases in the surface area.

Microstructures

Photo.4: 100x, The photo was taken from surface to core of the specimen. At the surface, the microstructure become Pearlite because of increasing carbon.

Photo.5: 1000x, At the carburized surface of the specimen, the original strucutre are Ferrite and Pearlite , now no more free Ferrite because of carburization.

100x，该图为样本从表面到芯的照片。在其表面，该显微结构由于含碳量增大而变成珠光体。

1000x，在样本的渗碳表面，其原始结构为铁素体和珠光体，而现在，由于渗碳而使游离铁素体不复存在。

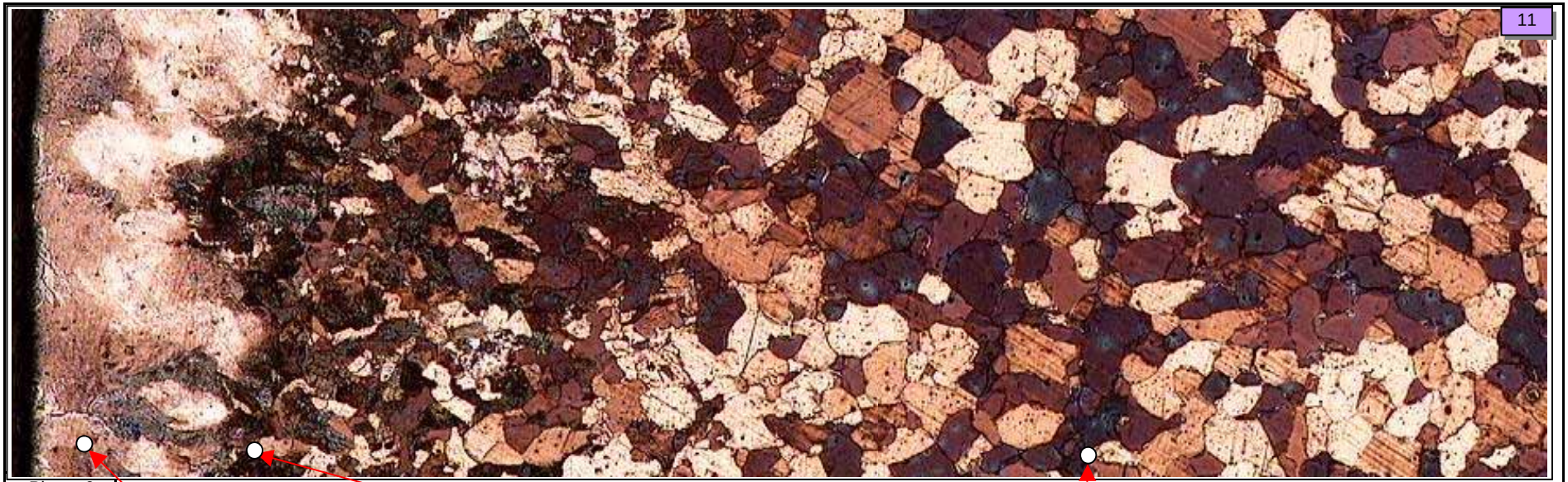


Photo. 6

Photo.7

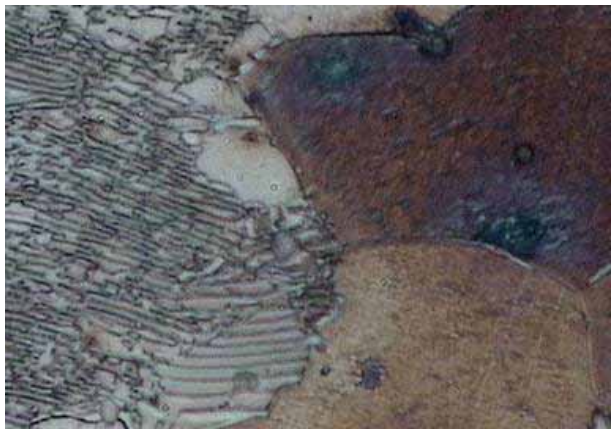


Photo.8

Photo.9

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, Fe_3C, and Ferrite (see Photo.7). Below the surface, the strucutres 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).

图7、8、9：
钢铁的原始显微结构为铁素体和珠光体。经渗碳，碳从表面扩散至芯。表面的结构变成含有渗碳体、Fe3C及铁素体的珠光体（见图7）。在表面以下，该结构含有珠光体和铁素体（见图8），而在芯处，该结构没有变化，仍然是原始条件下的珠光体和铁素体（见图9）。

Record of Microstructures

Specimen No.: 3	Specimen name	Material	Condition
	Ferrous Metal	Low carbon steel	Carburized, quenched and tempered

Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.18-0.23	0.15-0.35	0.30-0.60	0.04 max	0.04max	-	-	-	-	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	GOST1050	GB 699	SS14	JIS	UNI5598	AS1442	BS
	1020	A29:1020	1.0402	-	CC20	20	20	1450	S20C	3CD20	CS1020	BS970:040A20

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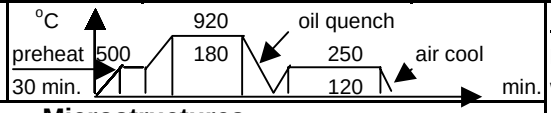
	Soaking time, min.	1/2hr./25 mm.+1 hr.		depend on case depth.	2 hrs min.	depend on case depth.	2 hrs min.	
	Quenching medium	air or nitrogen		oil	air	oil	air	
	Hardness	120-130 HB		60-62 HRC	55-60 HRC	60-62 HRC	55-60 HRC	

Final heat treatment process of this specimen



Process: The specimen is heated to 920°C for180 min.in atmosphere controlled furnace with carbon potential o.9%. C atom diffused into specimen surface and combinded with Fe to form Fe_3C(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

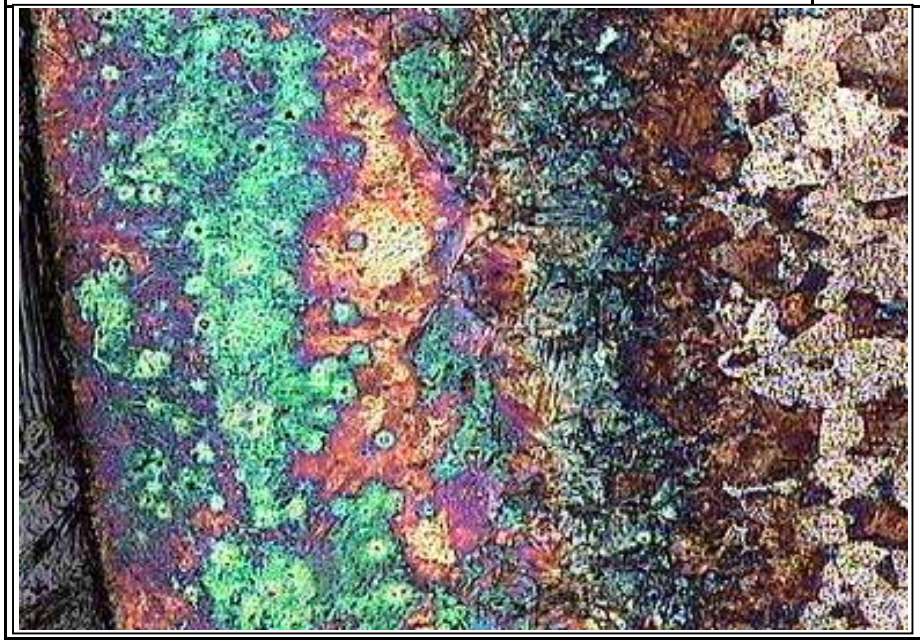


Photo.10: 50x,The specimen was carburized, quench, and tempered. Pearlite at the surface and below surface transformed to Martensite(left, colorfull area)

图10：50x， 该样本经渗碳、淬火及回火处理。表面及表面以下的珠光体转化为马氏体（左侧彩色区域）。

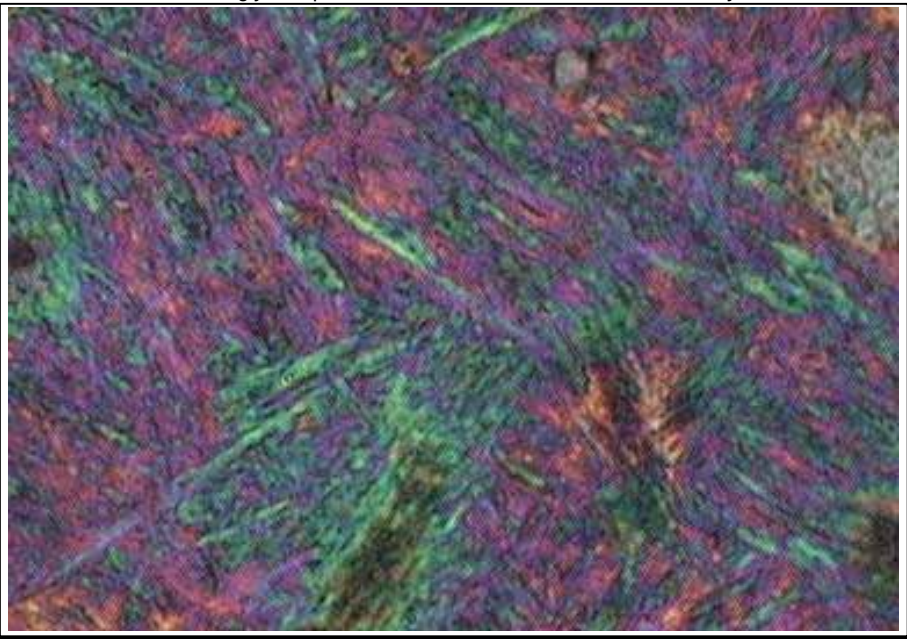


Photo.11: 1000x, At the case area, the acicular or needle like structure(Martensite) will be seen(purple, green, and brown).

1000x，在该层区域中，将可看见针状结构（马氏体）（紫、绿和棕色）。

Photo.12,50x

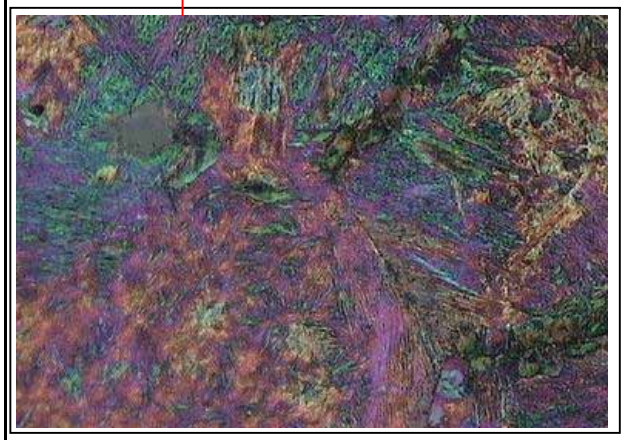


Photo.13 1000x

Photo.14 1000x

Photo.15 1000x

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).

图13、14、15：
1000x，图12所示为低碳钢经渗碳、淬火及回火处理之后从表面至芯的显微结构。绿、紫、黄色层为马氏体（见图13）。层与芯之间为马氏体与铁素体（见图14）。在芯处，该显微结构仍为原始状态的珠光体和铁素体，某些珠光体可能转化为马氏体，但铁素体仍保持不变（见图15）。

Record of Microstructures

Specimen No.: 4	Specimen name	Material	Condition
	Ferrous Metal	Low carbon steel	Carbonitrided, hardened and tempered

Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.18-0.23	0.15-0.35	0.30-0.60	0.04 max	0.04max	-	-	-	-	-	-	-	-

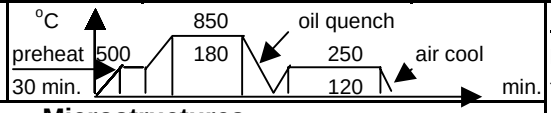
Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	GOST1050	GB 699	SS14	JIS	UNI5598	AS1442	BS
	1020	A29:1020	1.0402	-	CC20	20	20	1450	S20C	3CD20	CS1020	BS970:040A20

Characteristics: Most wildly used of several grade s containing about 0,20%carbon. Available in a variety of product forms. Excellent forgability and weldability. No preheating and post heating required before or after welding. Machinability is notably poor. Wildy 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	Descriptions \ Processes	Normalizing	Through hardening	Carburizing	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	925	Because of low carbon and no alloying element Through hardening is not advisable.	870-955	200-250	850-870	200-250	Nitriding is not recom-mended.
	Soaking time, min.	1/2hr./25 mm.+1 hr.		depend on case depth.	2 hrs min.	depend on case depth.	2 hrs min.	
	Quenching medium	air or nitrogen		oil	air	oil	air	
	Hardness	120-130 HB		60-62 HRC	55-60 HRC	60-62 HRC	55-60 HRC	

Final heat treatment process of this specimen



Process: The specimen is heated to 850°C for180 min.in atmosphere controlled furnace with carbon potential o.9%and some of NH_3 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

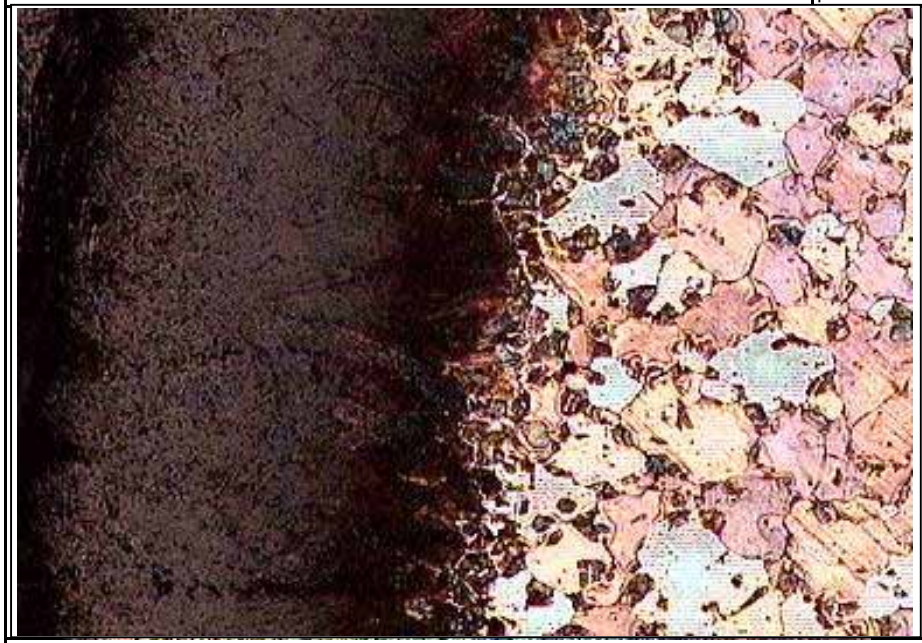


Photo.16: 50x, Cross-sectioned shows the microstructures from surface to core of the specimen. Dark case is Martensite, colorfull core are Pearlite and Ferrite.

50x, 横截面显示样本从表面到芯的显微结构。暗色层为马氏体，彩色芯为珠光体和铁素体

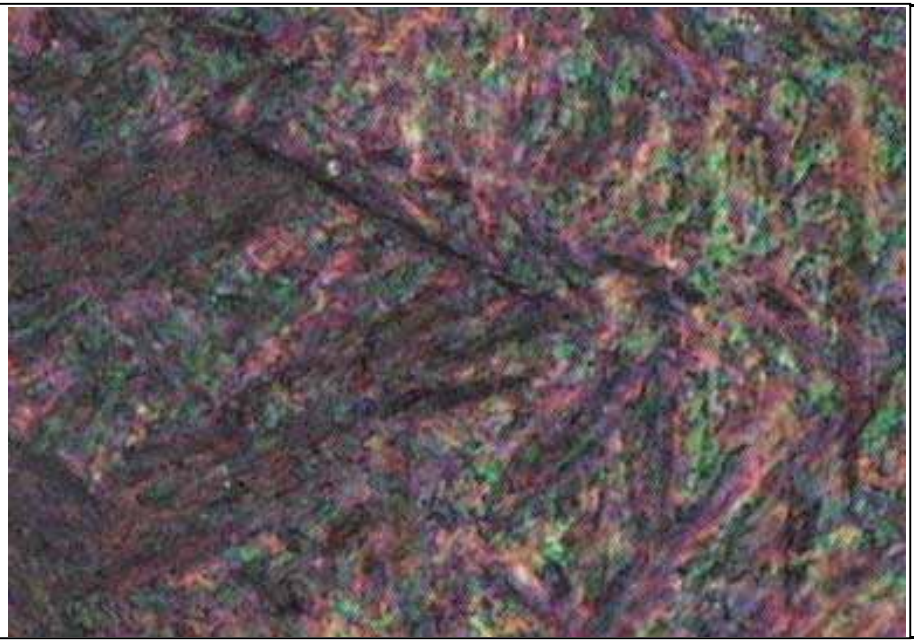


Photo.17: 1000x, Photo taken at the case, needlelike structure, Martensite.

1000x, 该层拍摄的照片，针状结构为马氏体。

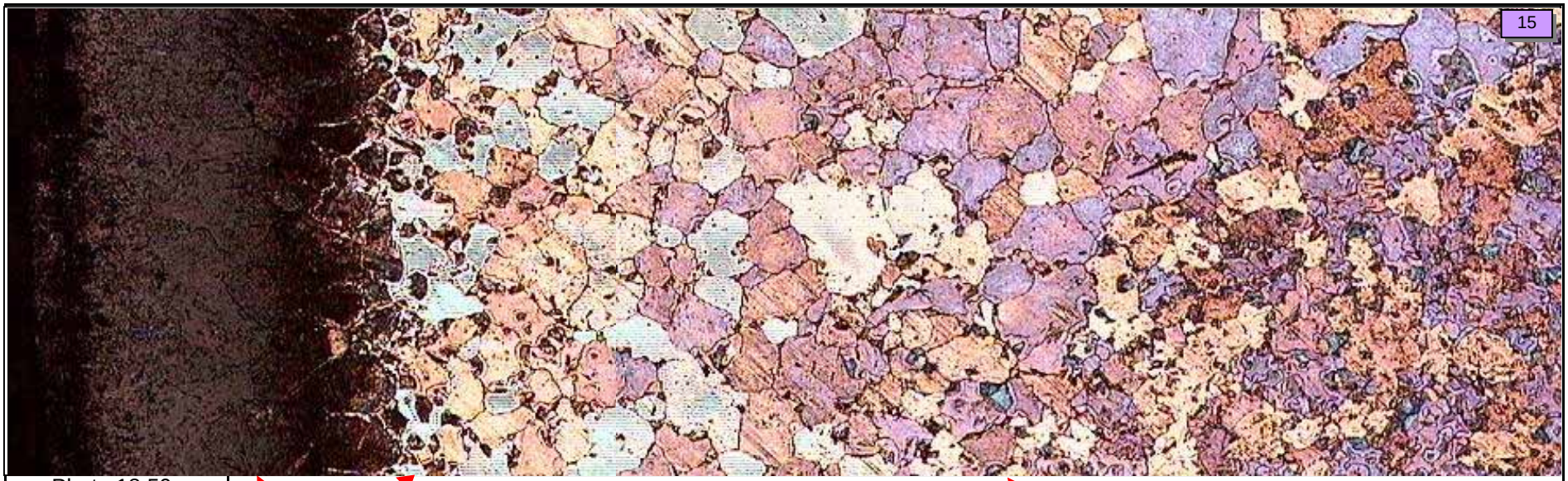
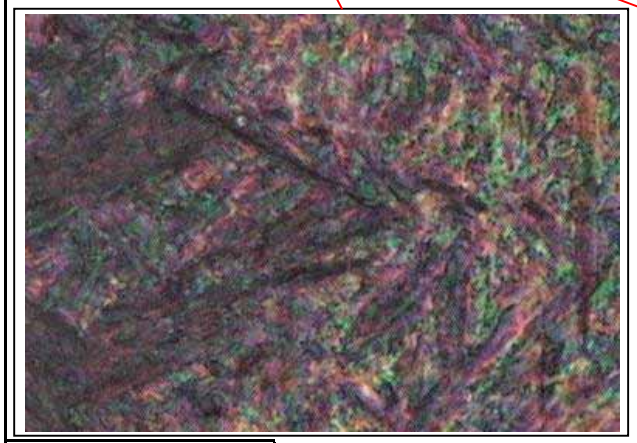


Photo.18:50x



:Photo.19:500x

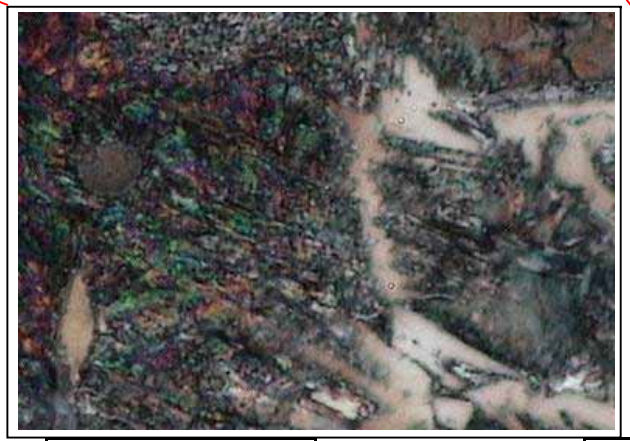


Photo.20:500x

Photo.21:500x

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).

图19、20、21：
500x, 图18所示为低碳钢经渗碳、淬火及回火处理之后从表面至芯的显微结构。该层包含马氏体（见图19）。层与芯之间由马氏体和铁素体组成（见图20）。在芯处，为原始显微结构，珠光体和铁素体仍保持不变（见图21）。

Record of Microstructures

Specimen No.: 5	Specimen name	Material	Condition	16
	Ferrous Metal	Medium carbon steel	Annealed	

Chemical	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
composition	0.50-0.60	0.15-0.35	0.60-0.90	0.04 max	0.045max	-	-	-	-	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	GOST1050	GB 699	SS14	JIS	UNI5598	AS1442	BS 1429
	1055	A29:1055	1.1209,CM55	CM55	CX55	55	55	1665	S53C	3CD55	K1055	En55

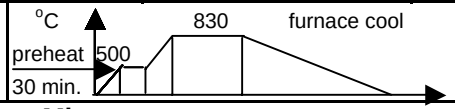
Characteristics: When heat treated, this steel yield a high surface hardness, combinded with relative good toughness. This grade also has good forging characteristics. It is shallow hardening, however, and useful section size is limited. Part made from AISI1055 steel requiring strength are oil quenched; parts requiring high hardness are water quench.

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

Heat treatment guide

Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Carbonitriding	Tempering	Nitriding
Temperature, °C	900	830	830	250-450	850-870	200-250	Nitriding is not recom-mended.
Soaking time, min.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	depend on case depth.	2 hrs min.	depend on case depth.	2 hrs min.	
Quenching medium	air or nitrogen	furace cool	oil or water	air	oil	air	
Hardness	180-200 HB	197 HB	60-64 HRC	60-40 HRC	60-62 HRC	60 HRC	

Final heat treatment process of this specimen



Process: The specimen is heated to 830°C, soaking time should be at 1/2 hour per inch of thickness plus 1 hour minmum and furnace cool to 650°Cat a rate not exceed 28°C per hour. Microstructures consist of pearlite and ferrite. Low hardenability, good forgability, poor machinability, not recommend for welding.

Microstructures

Photo.22: 100x, Medium carbon steel,annealed, consists of Pearlite and Ferrite.

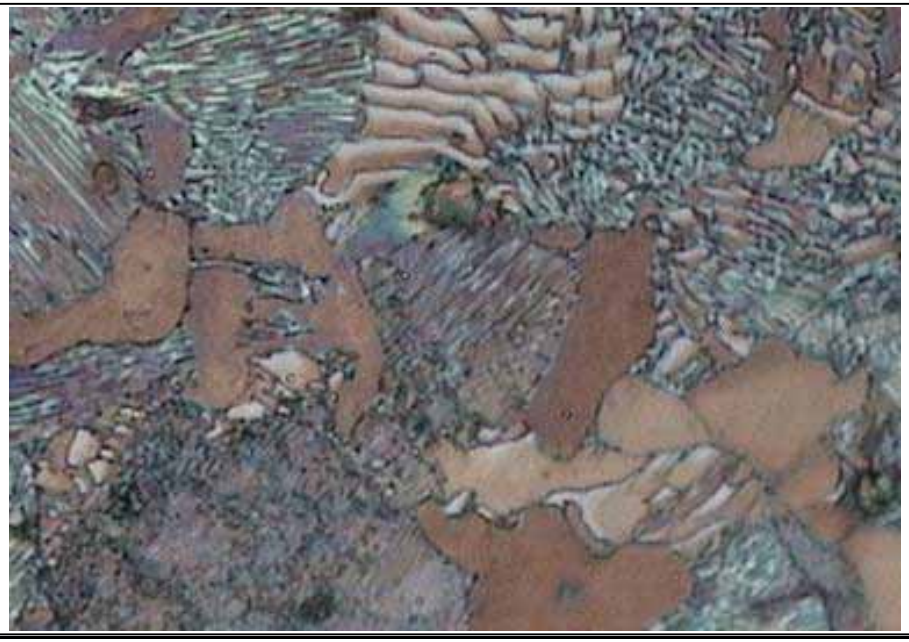


Photo.23: 1000x,Same as Photo.22, but in higher magnification. Light brown and brown area are Ferrite, green and purple area with small lines are Pearlite.

图22：
100x, 中碳钢，经过退火处理， 包含珠光体和铁素体。

1000x，与图22相同，但放大倍数更高。浅棕及棕色区域为铁素体，带有细线的绿和紫色区域为珠光体。

Photo.24: 500x, Same as in Photo.23, but in the larger area.The microstructures consist of Pearlite and Ferrite.

图24：500x，与图23相同，但面积更大。该显微结构包含珠光体和铁素体。

Record of Microstructures

Specimen No.: 6	Specimen name	Material	Condition
	Ferrous Metal	Medium carbon steel	Hardened by quenching, untempered

Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.50-0.60	0.15-0.35	0.60-0.90	0.04 max	0.045max	-	-	-	-	-	-	-	-

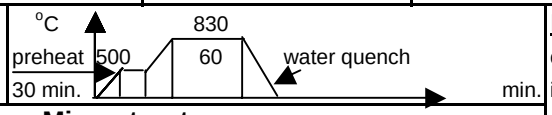
Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	GOST1050	GB 699	SS14	JIS	UNI5598	AS1442	BS 1429
	1055	A29:1055	1.1209,CM55	CM55	CX55	55	55	1665	S53C	3CD55	K1055	En55

Characteristics: When heat treated, this steel yield a high surface hardness, combinded with relative good toughness. This grade also has good forging characteristics. It is shallow hardening, however, and useful section size is limited. Part made from AISI1055 steel requiring strength are oil quenched; parts requiring high hardness are water quench.

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

Heat treatment guide	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	900	830	830	250-450	850-870	200-250	Nitriding is not recom-mended.
	Soaking time, min.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	depend on case depth.	2 hrs min.	depend on case depth.	2 hrs min.	
	Quenching medium	air or nitrogen	furace cool	oil or water	air	oil	air	
	Hardness	180-200 HB	197 HB	60-64 HRC	60-40 HRC	60-62 HRC	60 HRC	

Final heat treatment process of this specimen



Process: 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 stess, high hardness, brittle, not suitable for any application. Some Ferrite retained because of low hardenability of steel.

Microstructures

Photo.25: 100x, Medium carbon steel, heated to 830oC and quenched in water, micro-

图25：
100x，中碳钢，加热至830℃并在水中淬火， 该显微结构包含马氏体，某些铁素体由于低淬透性而保持不变。

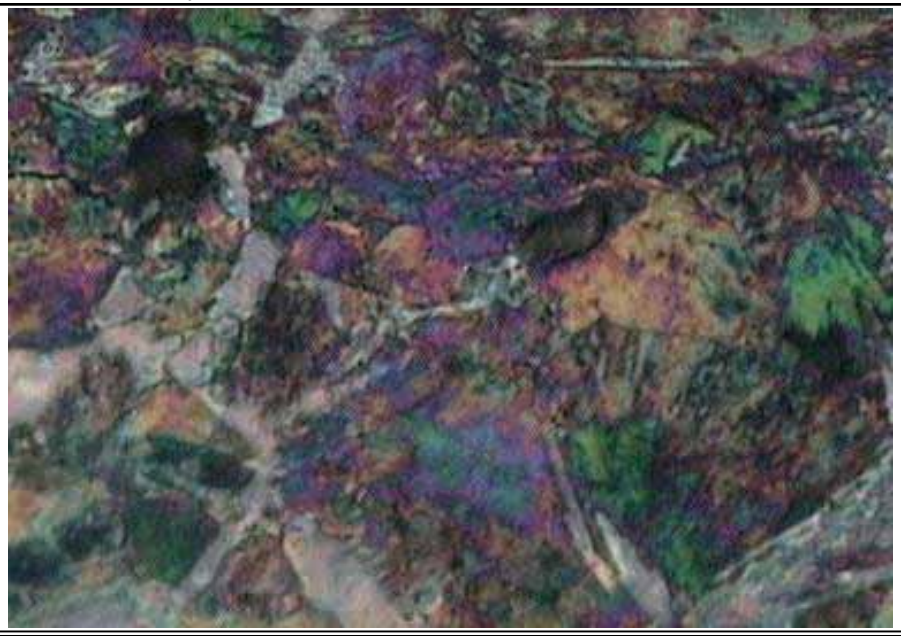


Photo.26: 1000x, Green,purple and blue area are Martensite, bright gray area are Ferrite.

图26：
1000x, 绿、紫和蓝色区域为马氏体，亮灰色区域为铁素体。

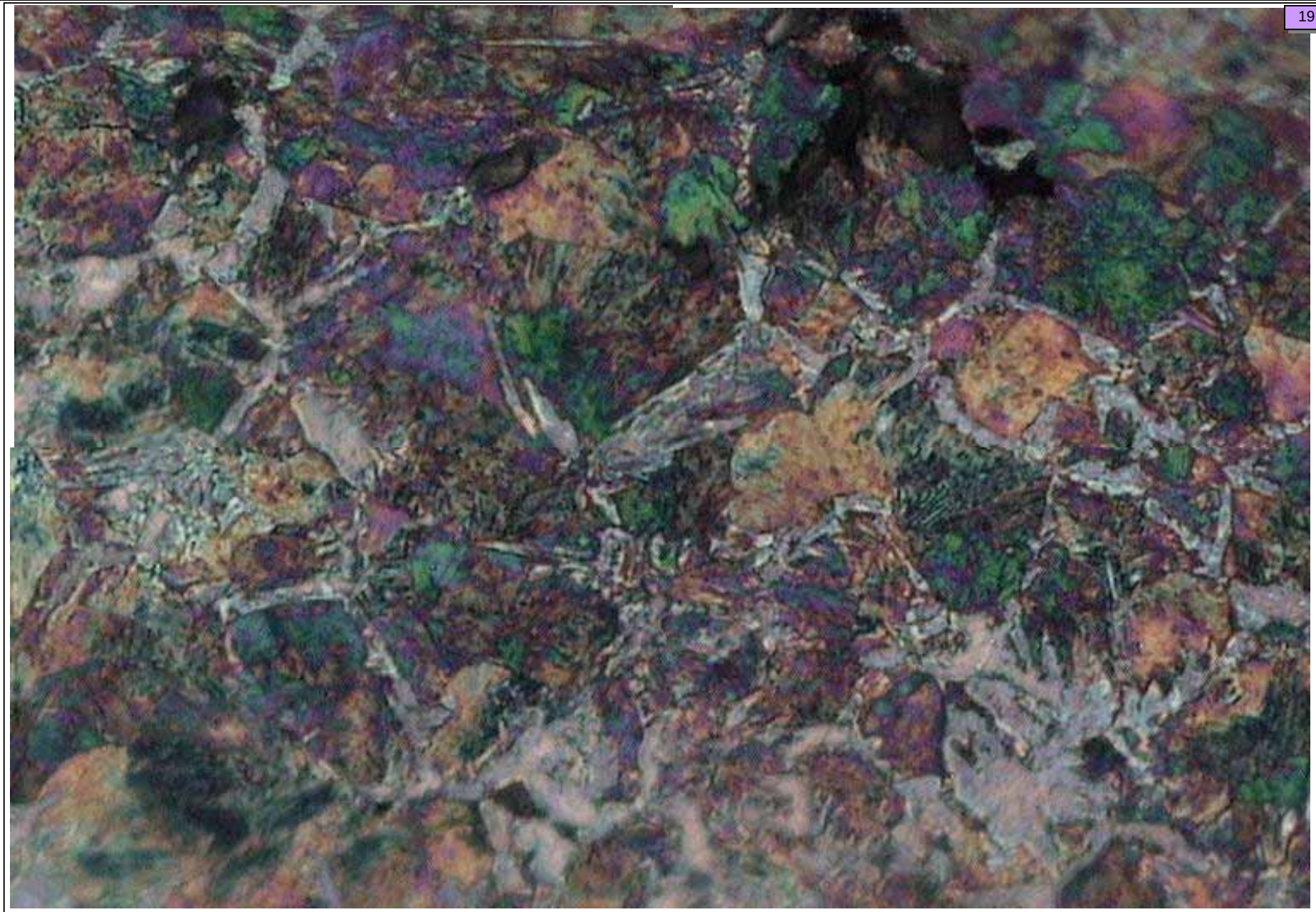


Photo.27: 1000x, Same as in Photo.26, but in larger area. The microstructures consist of Martensite and un-changed Ferrite.

图27：
1000x，与图26相同，该显微结构包含马氏体以及未变化的铁素体。

Record of Microstructures

Specimen No.: 7	Specimen name	Material	Condition
	Ferrous Metal	Medium carbon steel	Hardened by quenching and tempering

Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.50-0.60	0.15-0.35	0.60-0.90	0.04 max	0.045max	-	-	-	-	-	-	-	-

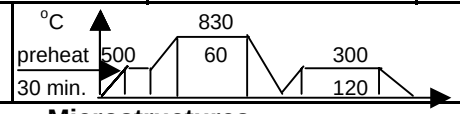
Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	GOST1050	GB 699	SS14	JIS	UNI5598	AS1442	BS 1429
	1055	A29:1055	1.1209,CM55	CM55	CX55	55	55	1665	S53C	3CD55	K1055	En55

Characteristics: When heat treated, this steel yield a high surface hardness, combinded with relative good toughness. This grade also has good forging characteristics. It is shallow hardening, however, and useful section size is limited. Part made from AISI1055 steel requiring strength are oil quenched; parts requiring high hardness are water quench.

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

Heat treatment guide	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	900	830	830	250-450	850-870	200-250	Nitriding is not recom-mended.
	Soaking time, min.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	depend on case depth.	2 hrs min.	depend on case depth.	2 hrs min.	
	Quenching medium	air or nitrogen	furace cool	oil or water	air	oil	air	
	Hardness	180-200 HB	197 HB	60-64 HRC	60-40 HRC	60-62 HRC	60 HRC	

Final heat treatment process of this specimen



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

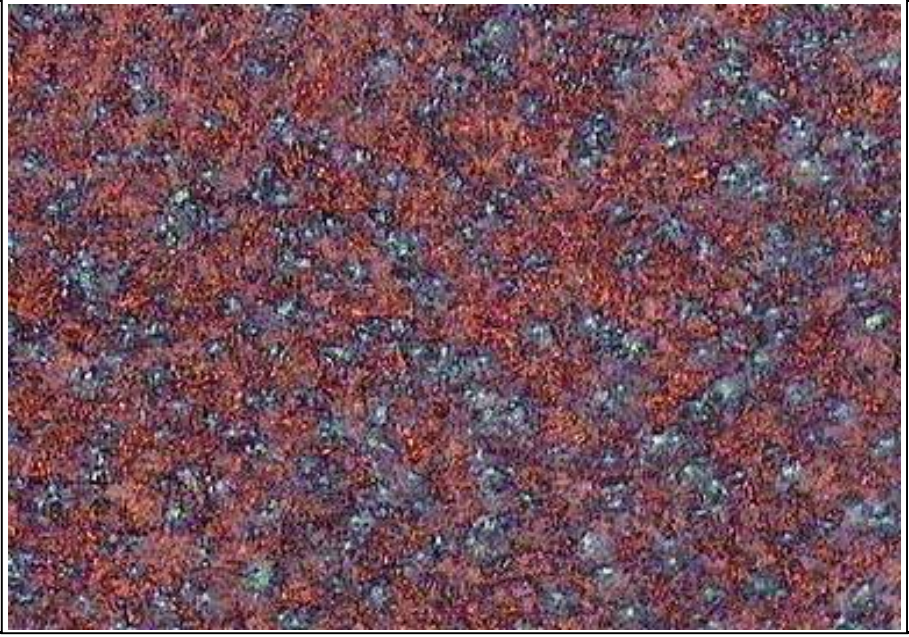


Photo.28: 100x, Medium carbon steel, quenched and tempered, microstructures consist of tempered Martensite, small dark dots are inclusions in steel.

图28：
100x, 中碳钢，经淬火及回火处理，该显微结构包含回火过的马氏体，小暗点为钢铁中的夹杂物。

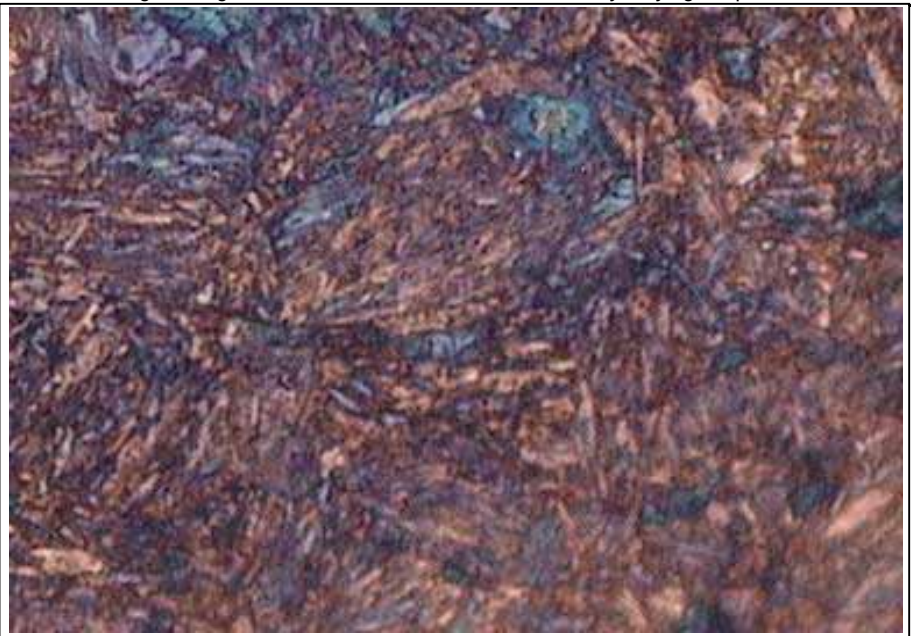


Photo.29: 1000x, Same as in Photo.28, but in higher magnification. Tempered Martensite are clearly seen.

图29：
1000x，与图28相同，但放大倍数更高。经回火处理过的马氏体清晰可见。

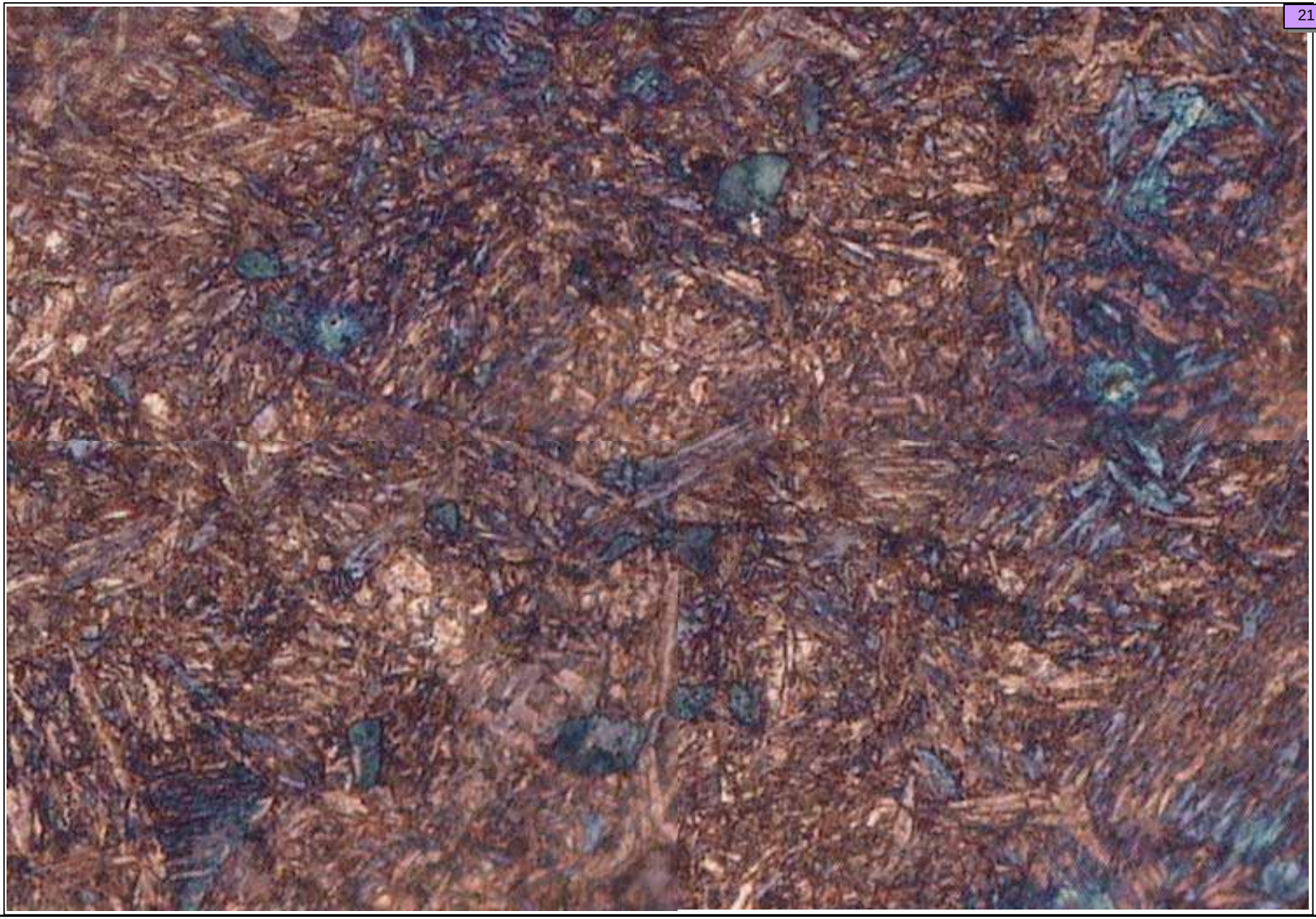


Photo.30: 1000x, Same as in Photo.29, but in larger area. The microstructures consist of tempered martensite.

图30：
1000x，与图29相同，但面积更大。该显微结构包含经回火处理过的马氏体。

Record of Microstructures

Specimen No.: 8	Specimen name	Material	Condition
	Ferrous Metal	High carbon steel	Annealed

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

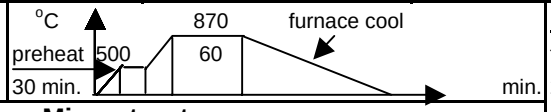
Similar steels	USA		GERMANY		FRANCE	INDIA	POLAND	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	IS 1570	PN84028	SS14	JIS G4801	UNI3545	AS1442	BS 1449
	1095	A510;A586	1.1275	-	CX100	C98	DS105	1870	SUP 4	C100	K1095	95CS

Characteristics: The higher carbon of 1095 steel provides maximum surface hardness with improved wear resistance and high strength. Ther is, however, a loss of toughness. Because cold forming methods are not suitable for this steel, uses are limitted 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	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Austempering
	Temperature, °C	855	800	800	370-675	800
	Soaking time, min.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	2 hrs min.	1/2hr./25 mm.+1 hr.
	Quenching medium	air or nitrogen	furnace cool	oil or water	air	salt bath at 315°C, 2 hrs., air cool
	Hardness	269-290 HB	269-290 HB	63-66 HRC	27-43 HRC	63-66 HRC

Final heat treatment process of this specimen



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

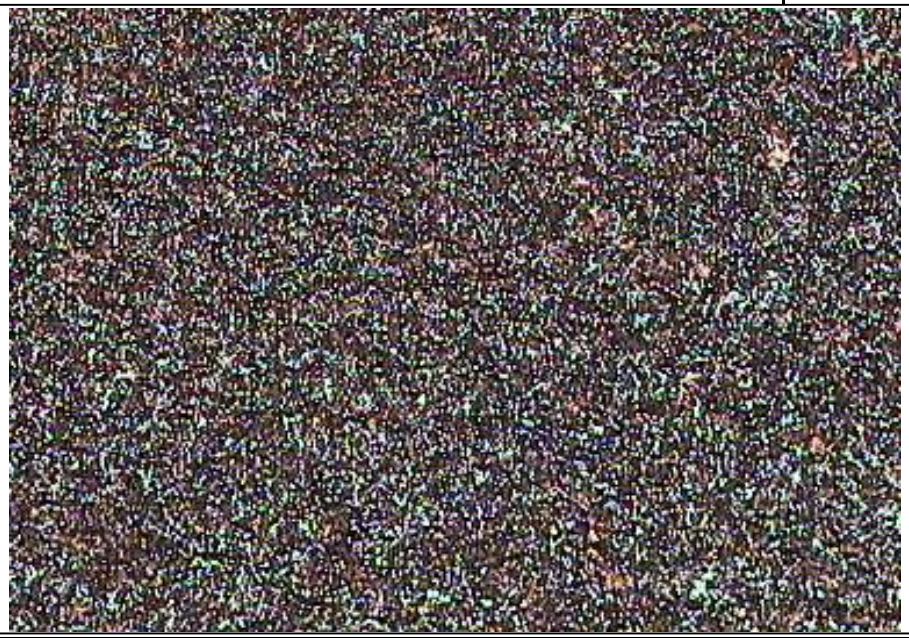


Photo.31: 100x, The microstructures consist of Pearlite and carbides

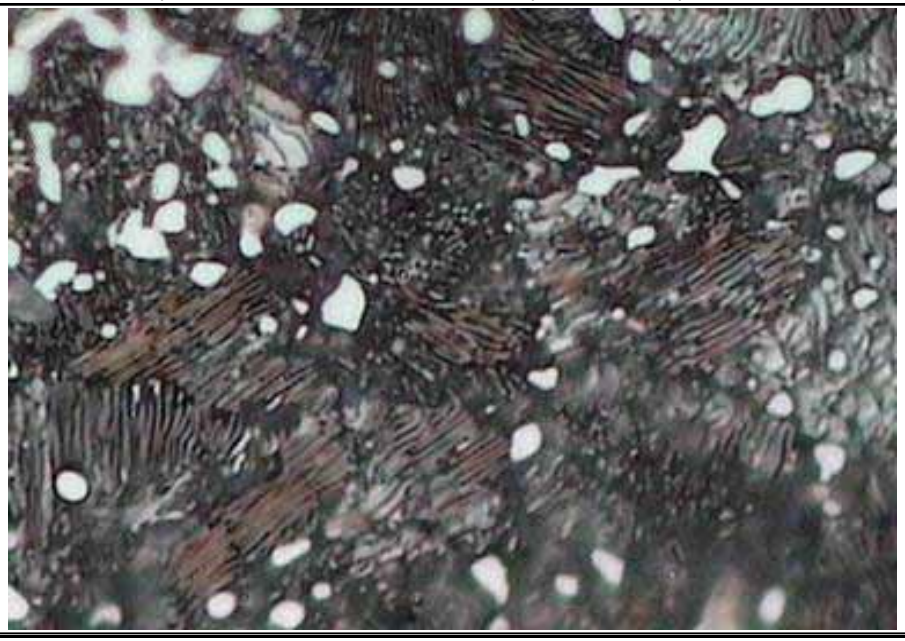


Photo.32: 1000x,Same as in Photo.31, but in higher magnification. The matrix is Pearlite. white particles are carbides or Cementite, Fe_3C.

图31：
100x，该显微结构包含珠光体及各种碳化物。

图32：1000x，与图31相同，但放大倍数更高。该基体为珠光体，白色颗粒为各种碳化物或渗碳体和Fe3C。

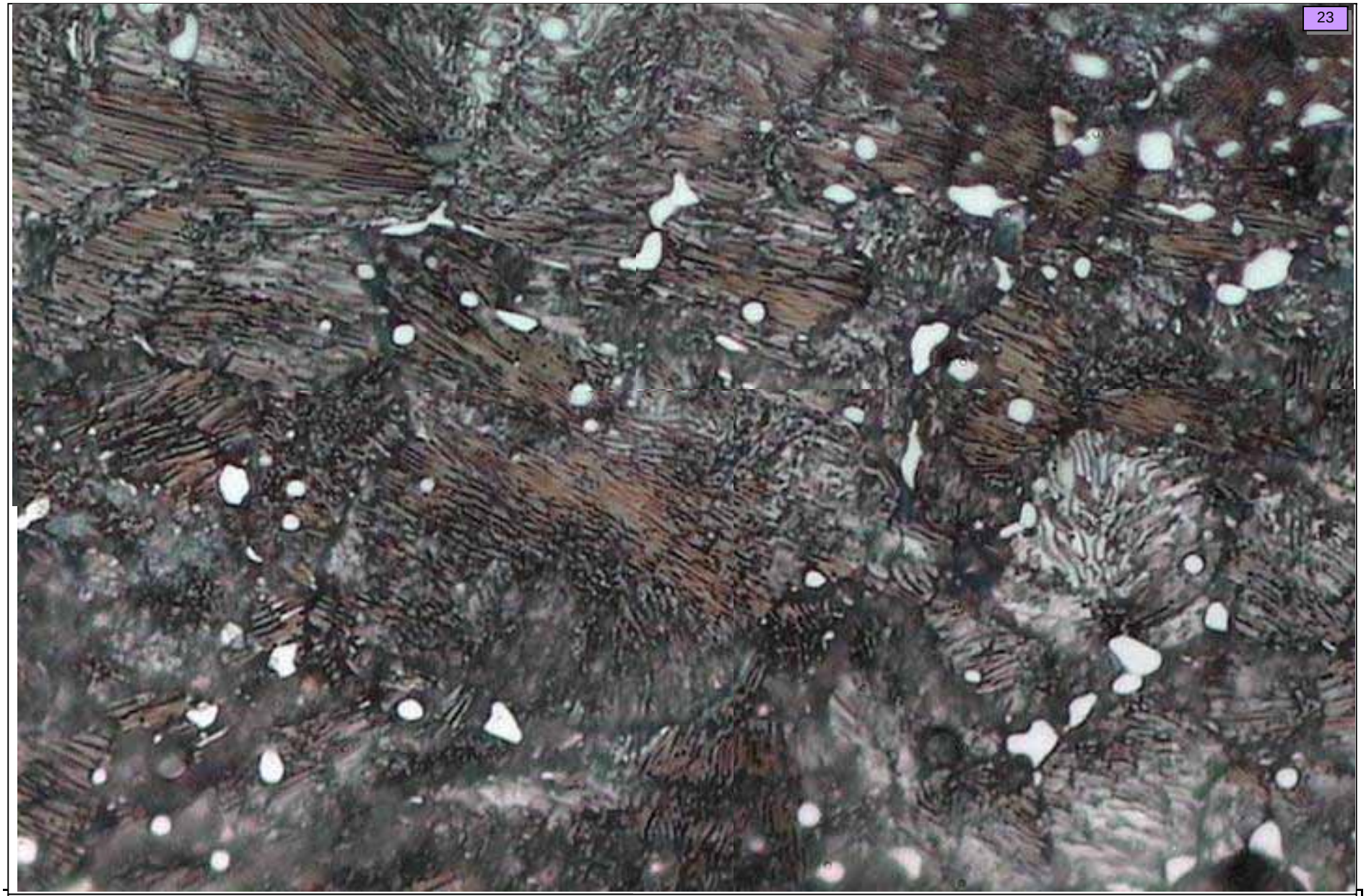


Photo.33:1000x, Same as in Photo.32, but in larger area. Microstrucutres consist of Pearlite matrix and Carbides particles.

图33：
1000x，与图32相同，但面积更大。该显微结构包含珠光体基体和各种碳化物颗粒。

Record of Microstructures

Specimen No.: 9	Specimen name	Material	Condition
	Ferrous Metal	High carbon steel	Hardened by quenching, untempered

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

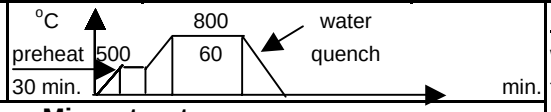
Similar steels	USA		GERMANY		FRANCE	INDIA	POLAND	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	IS 1570	PN84028	SS14	JIS G4801	UNI3545	AS1442	BS 1449
	1095	A510;A586	1.1275	-	CX100	C98	DS105	1870	SUP 4	C100	K1095	95CS

Characteristics: The higher carbon of 1095 steel provides maximum surface hardness with improved wear resistance and high strength. Ther is, however, a loss of toughness. Because cold forming methods are not suitable for this steel, uses are limitted 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	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Austempering
	Temperature, °C	855	800	800	370-675	800
	Soaking time, min.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	2 hrs min.	1/2hr./25 mm.+1 hr.
	Quenching medium	air or nitrogen	furnace cool	oil or water	air	salt bath at 315°C, 2 hrs., air cool
	Hardness	269-290 HB	269-290 HB	63-66 HRC	27-43 HRC	63-66 HRC

Final heat treatment process of this specimen



Process: 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 brittlle. 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.

100x，该显微结构包含马氏体和各种碳化物。

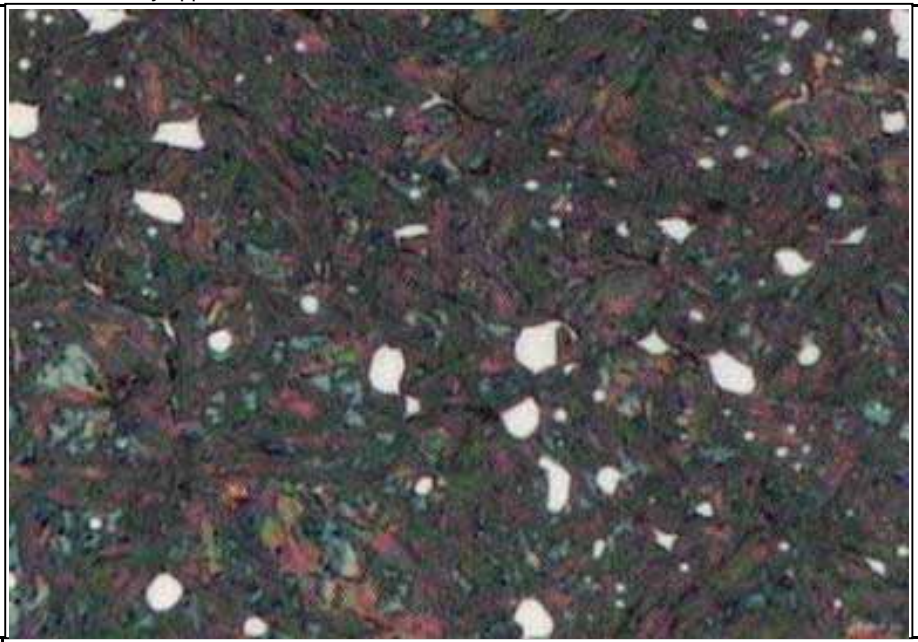


Photo.35: 1000x, Same as in photo.34, but in higher magnification. Acicular structure is Martensite and white particles are carbides. Light blue area are retained Austenite.

1000x，与图34相同，但放大倍数更高。针状结构为马氏体，白色颗粒为各种碳化物。浅蓝色区域为残余奥氏体。

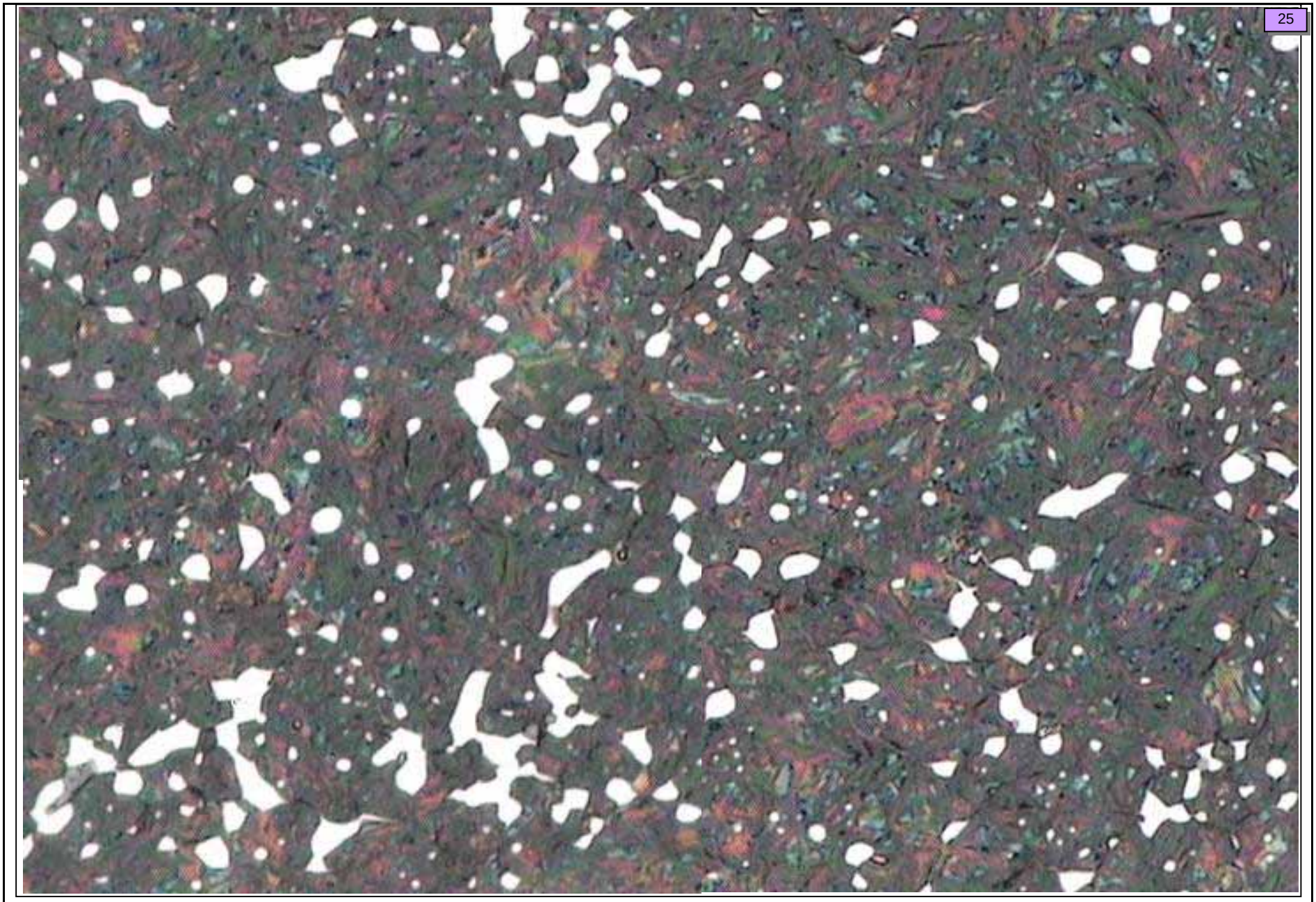


Photo.36: 1000x, Same as in Photo.35, but in larger area. The microstructures consist of Martensite, Carbides and retained Austenite.

图36：
1000x，与图35相同，但面积更大。该显微结构包含马氏体、各种碳化物以及残余奥氏体

Record of Microstructures

Specimen No.: 10	Specimen name	Material	Condition
	Ferrous Metal	High carbon steel	Hardened by quenching, tempered

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

Similar steels	USA		GERMANY		FRANCE	INDIA	POLAND	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	IS 1570	PN84028	SS14	JIS G4801	UNI3545	AS1442	BS 1449
	1095	A510;A586	1.1275	-	CX100	C98	DS105	1870	SUP 4	C100	K1095	95CS

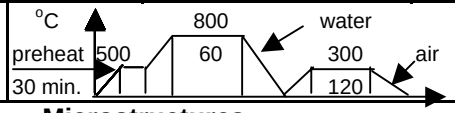
Characteristics: The higher carbon of 1095 steel provides maximum surface hardness with improved wear resistance and high strength. Ther is, however, a loss of toughness. Because cold forming methods are not suitable for this steel, uses are limitted to flat stampings and springs coiled from small diameter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

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

Heat treatment guide

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

Final heat treatment process of this specimen



Process: 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 brittlle. The specimen was reheated to 300oC for 120 minutes, the hardness and brittleness will be decreased and toughness increased.

Microstructures

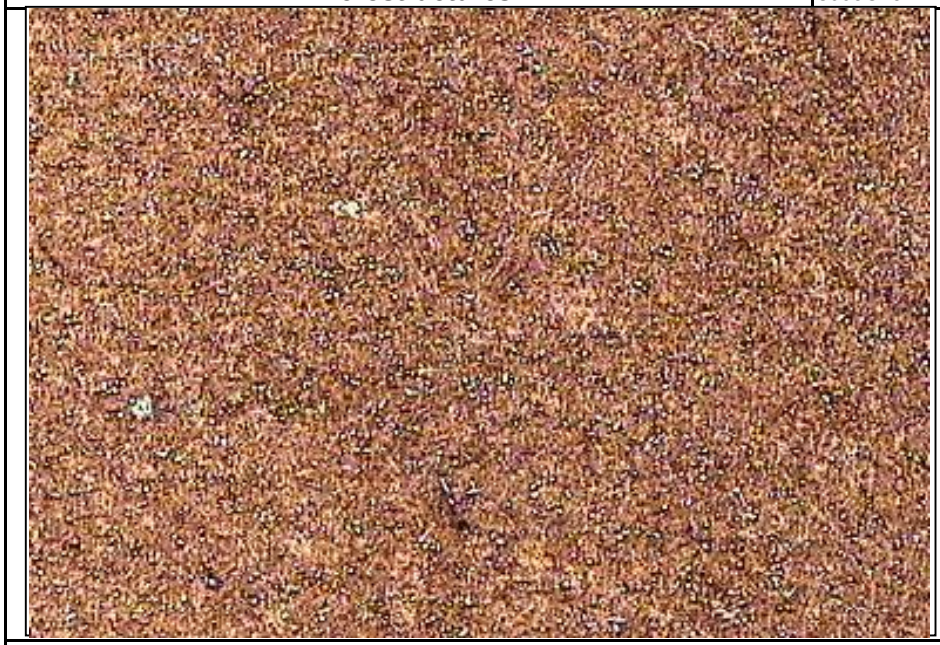


Photo.37: 100x, The microstructures consist of Martensite, and carbides.

图37：
100x，该显微结构包含马氏体和各种碳化物。

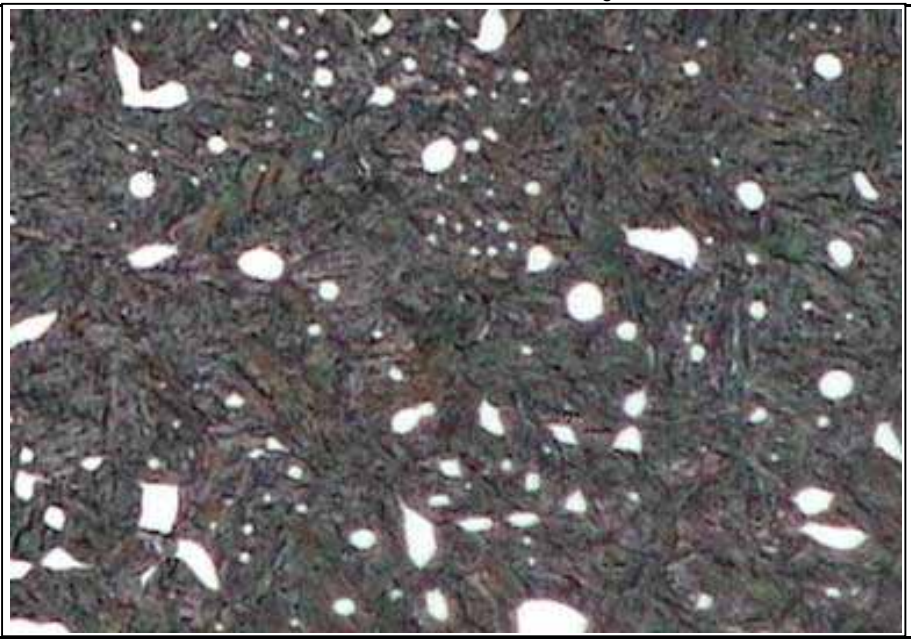


Photo.38: 1000x, Same as in Photo.37, but in higher magnification.The matrix is Martensite White particles are carbides.

图38：1000x，与图35相同，但放大倍数更高。基体为马氏体，白色颗粒为各种碳化物。

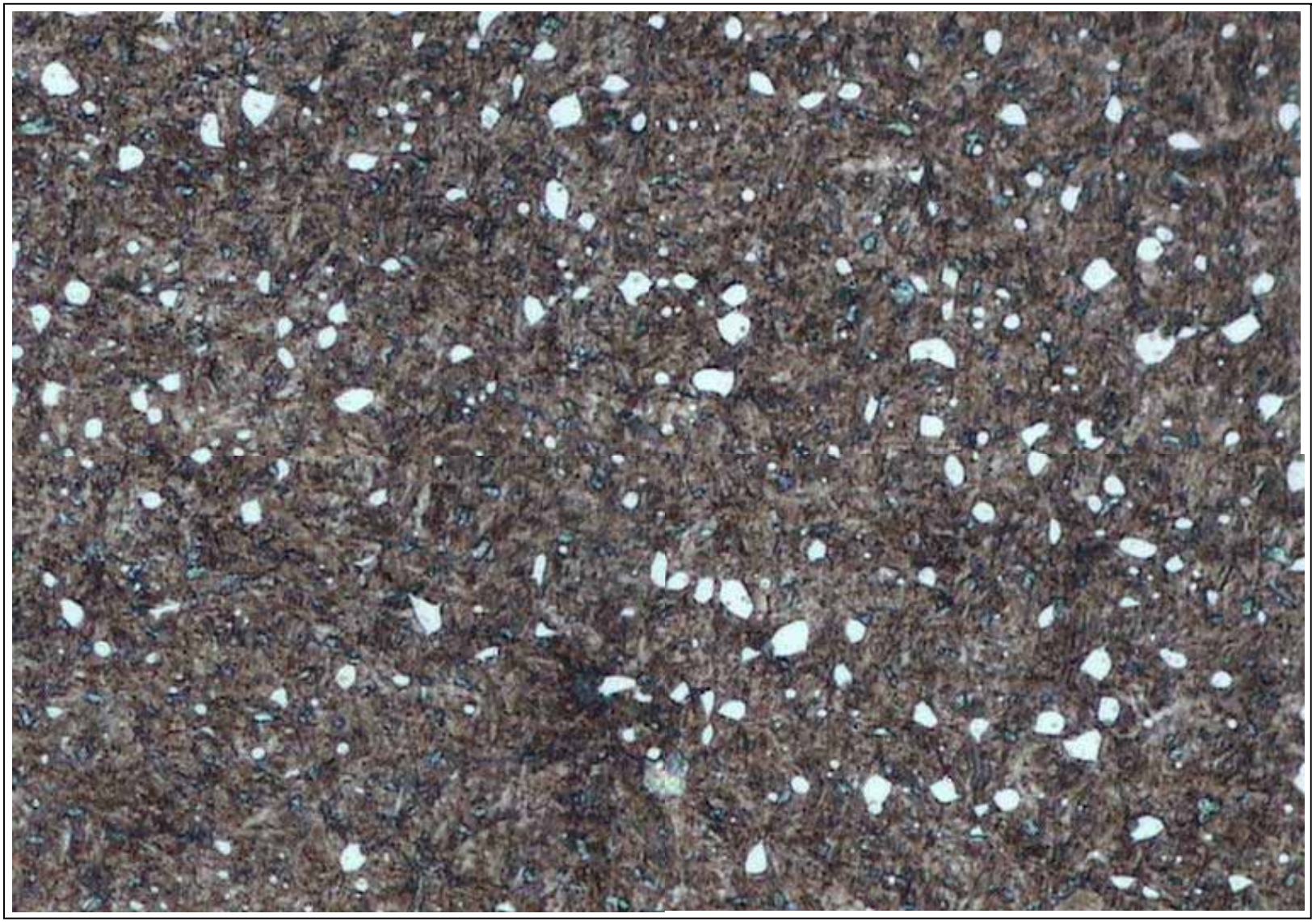


Photo.39: 1000x, Same as in Photo.38, but in larger area. The microstructures consist of Martensite, and carbides.

图39：
1000x，与图38相同，但面积更大。该显微结构包含马氏体和各种碳化物。

Record of Microstructures

Specimen No.: 11	Specimen name	Material	Condition
	Ferrous Metal	High carbon steel	Annealed, for inclusion investigation

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

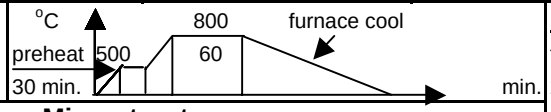
Similar steels	USA		GERMANY		FRANCE	INDIA	POLAND	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	IS 1570	PN84028	SS14	JIS G4801	UNI3545	AS1442	BS 1449
	1095	A510;A586	1.1275	-	CX100	C98	DS105	1870	SUP 4	C100	K1095	95CS

Characteristics: The higher carbon of 1095 steel provides maximum surface hardness with improved wear resistance and high strength. Ther is, however, a loss of toughness. Because cold forming methods are not suitable for this steel, uses are limitted 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	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Austempering
	Temperature, °C	855	800	800	370-675	800
	Soaking time, min.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	2 hrs min.	1/2hr./25 mm.+1 hr.
	Quenching medium	air or nitrogen	furnace cool	oil or water	air	salt bath at 315°C, 2 hrs., air cool
	Hardness	269-290 HB	269-290 HB	63-66 HRC	27-43 HRC	63-66 HRC

Final heat treatment process of this specimen



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

图40：
100x，为方便研究夹杂物，该样本未经侵蚀。黑点与棕色颗粒为嵌入钢铁中的夹杂物。

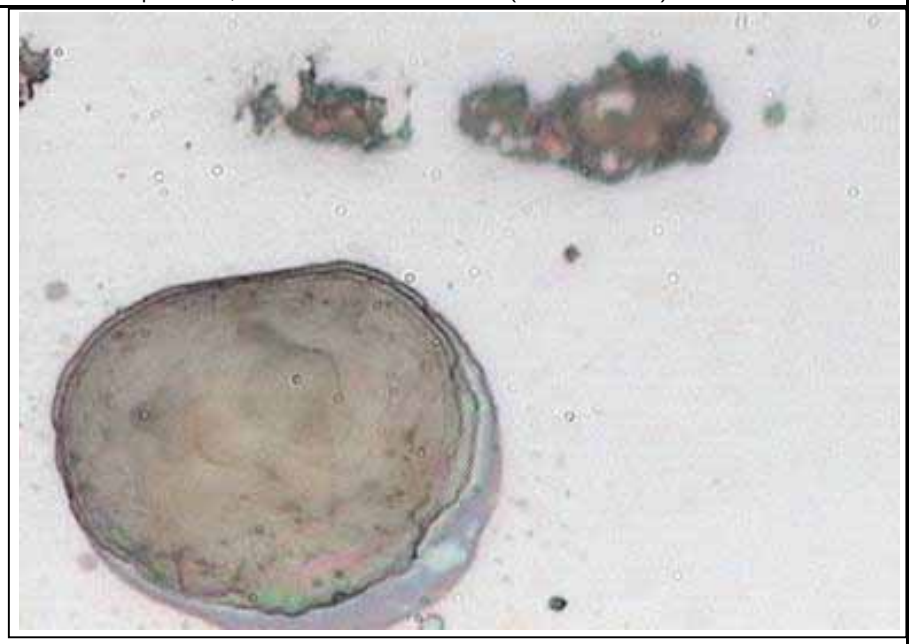


Photo.41: 1000x, Same as in Photo.40, but in higher magnification. Brown particles are non-metalic inclusion. These inclusions remained from the melting processes.

图41：1000x，与图40相同，但放大倍数更高。棕色颗粒为非金属夹杂物。这些夹杂物是从熔化工序中残留下来的。

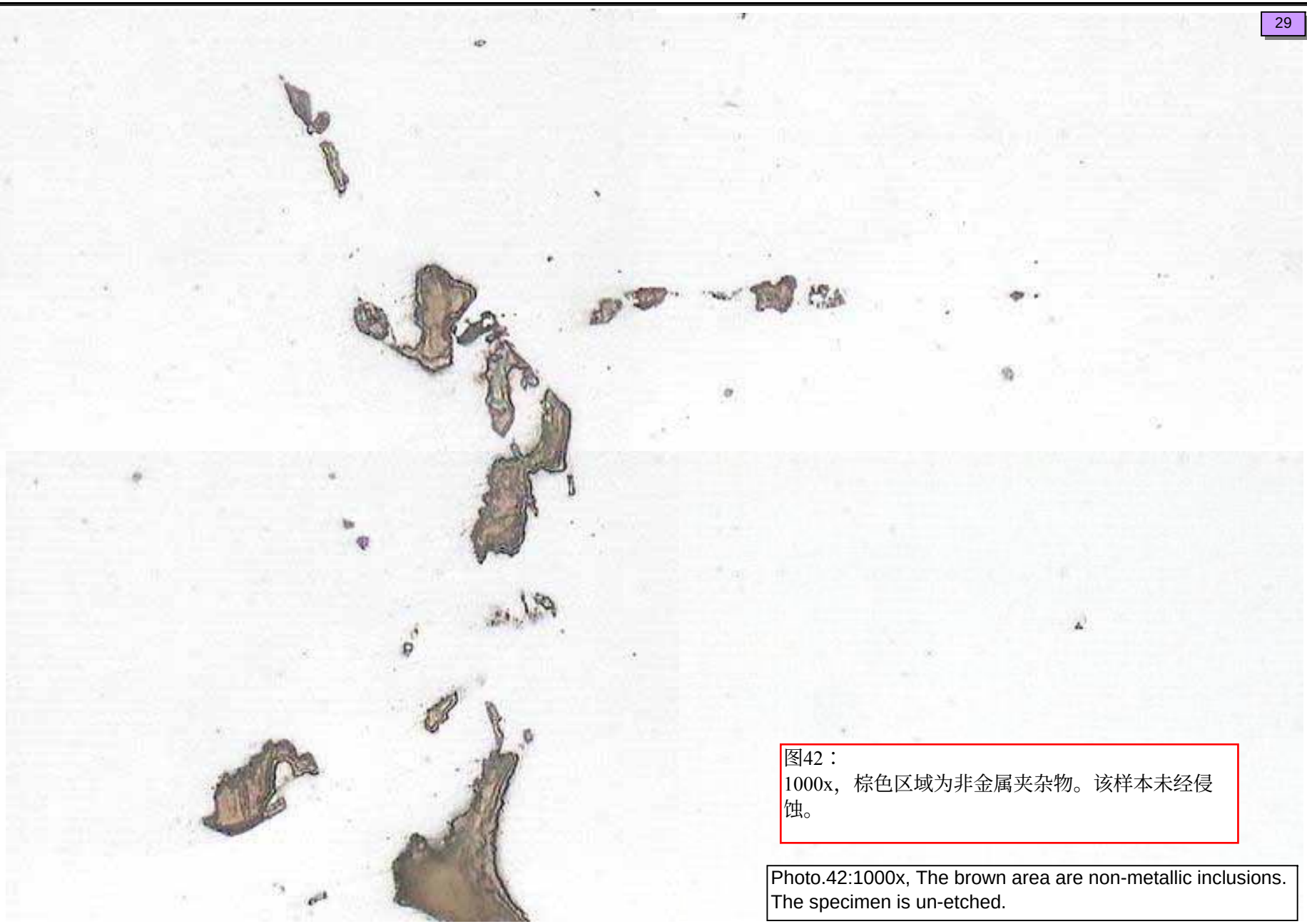


图42：
1000x，棕色区域为非金属夹杂物。该样本未经侵蚀。

Photo.42:1000x, The brown area are non-metallic inclusions. The specimen is un-etched.

Record of Microstructures

Specimen No.: 12	Specimen name	Material	Condition	30
	Ferrous Metal	AISI 4130	Annealed	

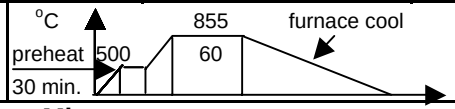
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.28-0.33	0.15-0.30	0.40-0.60	0.035 max	0.040max	0.80-1.10	0.15-0.25	-	-	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN17200	KRUPP	AFNOR	GOST4543	GB 3077	SS14	JIS G4105	UNI	AS1444	BS 1717
	4130	A29;A322	1.7218	7218	30CD4	30ChM	30CrMo	2233	SCM430	25CrMo4	4130	CDS110

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	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	900	855	880	250-650	850-870	200-250	Nitriding is not recom-mended.
	Soaking time, min.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	2 hrs min.	depend on case depth.	2 hrs min.	
	Quenching medium	air or nitrogen	furnace cool	oil or water	air or faster	oil	air	
	Hardness	163-217 HB	217 HB	45-50 HRC	48-22 HRC	60-62 HRC	58-60 HRC	

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.

图43：
100x, 该显微结构包含珠光体和铁素体。

图44： 1000x, 与图34相同，但放大倍数更高。暗棕色区域为珠光体，浅色区域为铁素体。

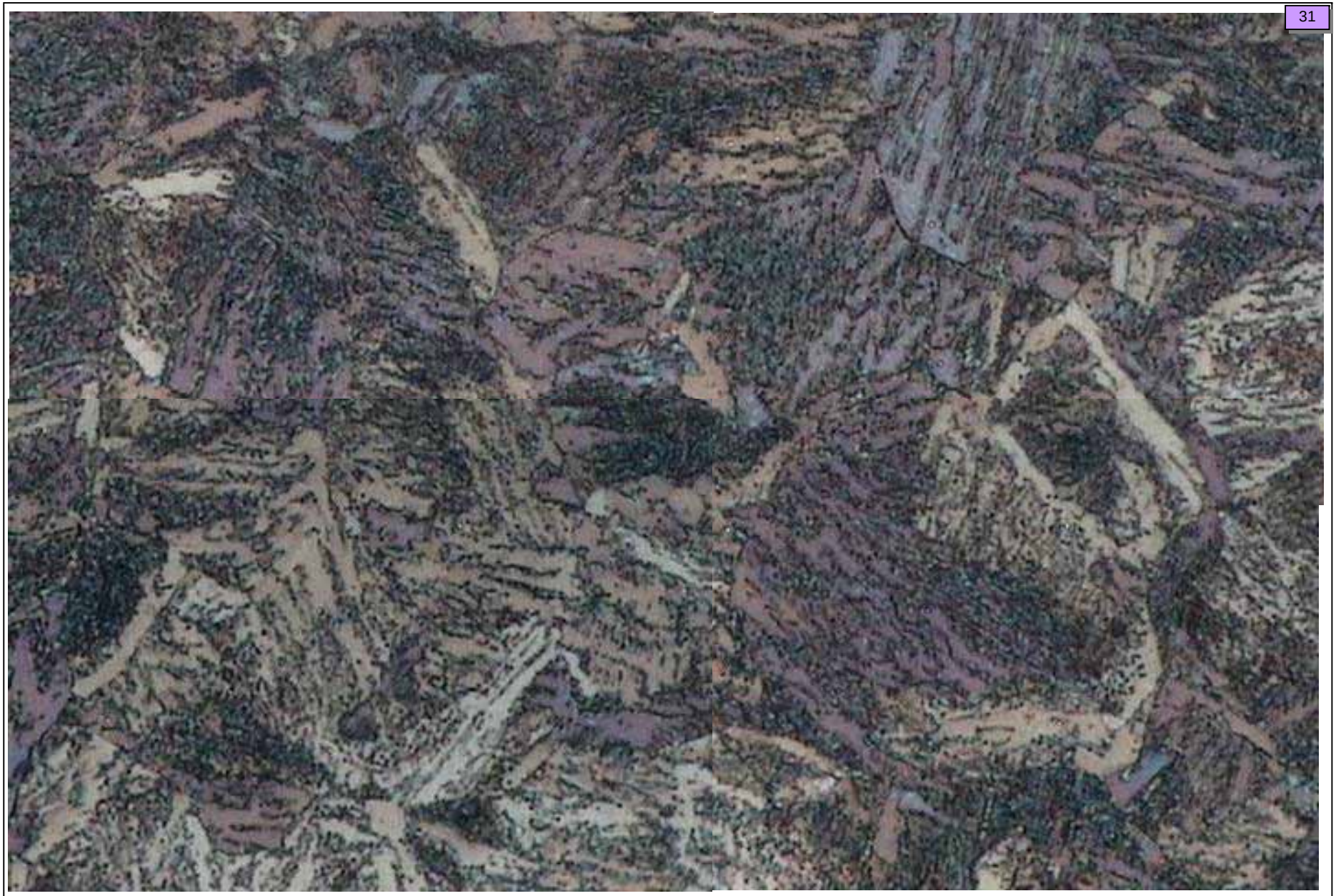


Photo.45:1000x, Same as in Photo.44, but in larger area. Light area are Ferrite, dark area are Pearlite.

图45：
1000x, 与图44相同，但面积更大。浅色区域为铁素体，暗色区域为珠光体。

Record of Microstructures

Specimen No.: 13	Specimen name	Material	Condition
	Ferrous Metal	AISI 4130	Hardened by quenching and tempering

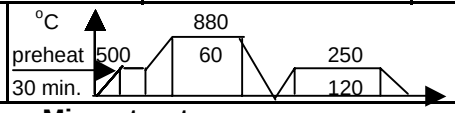
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.28-0.33	0.15-0.30	0.40-0.60	0.035 max	0.040max	0.80-1.10	0.15-0.25	-	-	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	GOST1050	GB 699	SS14	JIS	UNI5598	AS1442	BS 1449
	4130	A510;A586	1.1259	-	CX80	80	80	1778-02	S80C	3CD80	K1082	80CS

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	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	900	855	880	250-650	850-870	200-250	Nitriding is not recom-mended.
	Soaking time, min.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	2 hrs min.	depend on case depth.	2 hrs min.	
	Quenching medium	air or nitrogen	furnace cool	oil or water	air or faster	oil	air	
	Hardness	163-217 HB	217 HB	45-50 HRC	48-22 HRC	60-62 HRC	58-60 HRC	

Final heat treatment process of this specimen



Process: The specimen was heated at 880°C and soak for 120 minutes for austenitizing, the original microstructure will be transformed to austenite, then quench in water, austenite will be transformed to martensite, high strees, high hardness, then tempered at 250oC for 120 minutes. Martensite will be trans-formed to tempered martensite with lower hardness and higher toughness.

Microstructures

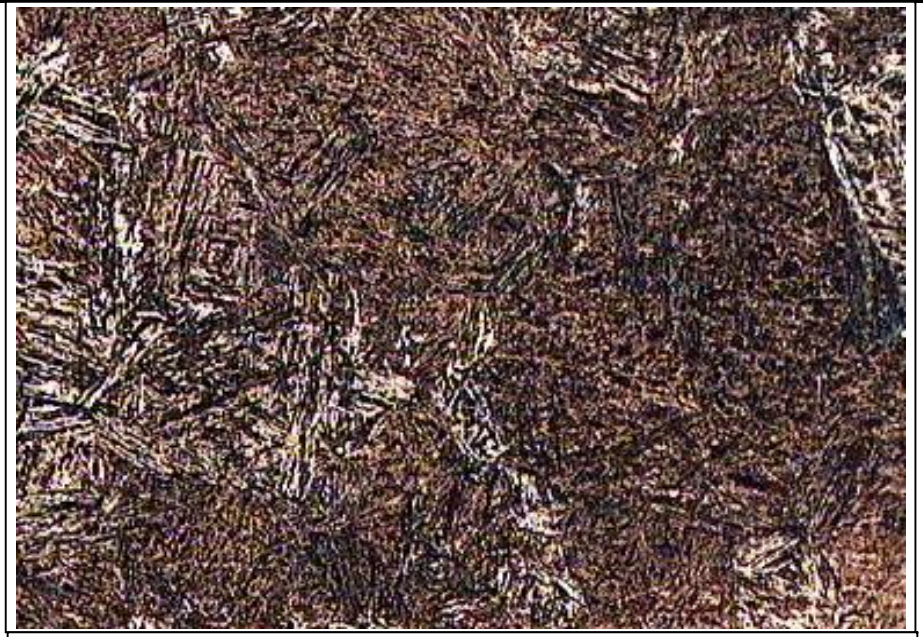


Photo.46:100x, Microstructure after quenching and tempering is Martensite.

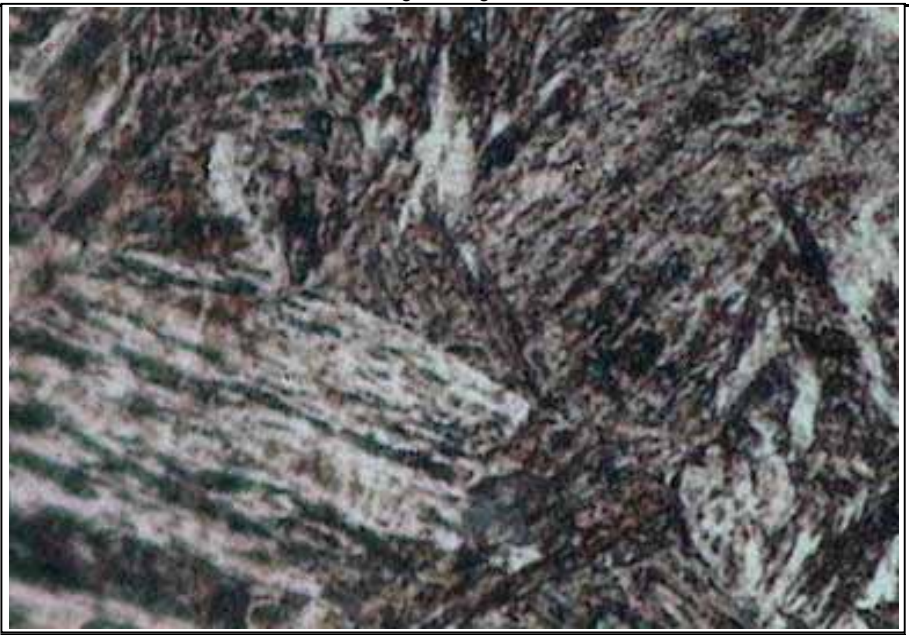


Photo.47:1000x, Same as in Photo.46, but in higher magnification.The structures are Martensite.

图46：
100x，经淬火、回火处理，该显微结构为马氏体。

图47：1000x，与图46相同，但放大倍数更高。该结构为马氏体。

Photo.48:500x, The microstructures are Martensite

图48：
500x, 该显微结构为马氏体。

Record of Microstructures

Specimen No.: 14	Specimen name	Material	Condition
	Ferrous Metal	AISI 4340	Annealed

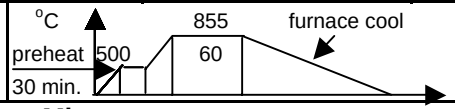
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.38-0.43	0.15-0.30	0.60-0.80	0.05 max	0.040max	0.70-0.90	0.20-0.30	1.65-2.00	-	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN	KRUPP	AFNOR	GOST1050	GB 699	SS14	JIS	UNI5332	AS1444	BS 4670
	4340	A29: 4340	1.6582	6582	-	-	-	1778-02	SNCM439	40NiCrMo7	4340	818Mo

Characteristics and applications: A high hardenabiliy 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 exibits good response to heat treatment and posses 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	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	900	855	880	250-650	850-870	200-250	Nitriding is not recom-mended.
	Soaking time, min.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	1/2hr./25 mm.+1 hr.	2 hrs min.	depend on case depth.	2 hrs min.	
	Quenching medium	air or nitrogen	furnace cool	oil or water	air or faster	oil	air	
	Hardness	163-217 HB	217 HB	45-50 HRC	48-22 HRC	60-62 HRC	58-60 HRC	

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

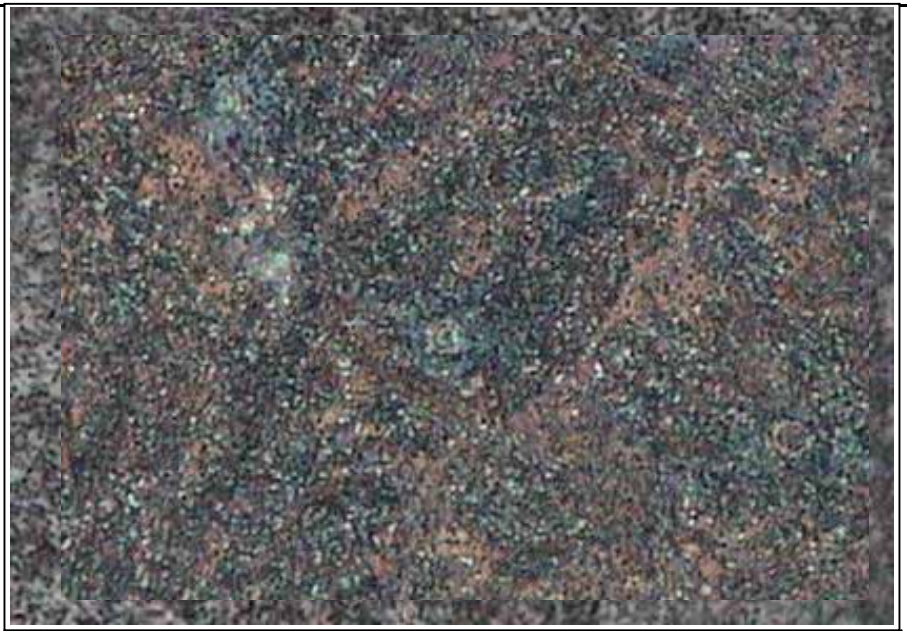


Photo.50: 1000x, Same as in Photo.49, but in higher magnification. Light area are Ferrite, dark area are Pearlite. Fine bright particles are Carbides.

图49：
100x, 该显微结构为珠光体及铁素体。

图50：1000x，与图49相同，但放大倍数更高。浅色区域为铁素体，暗色区域为珠光体。细亮区域为各种碳化物。

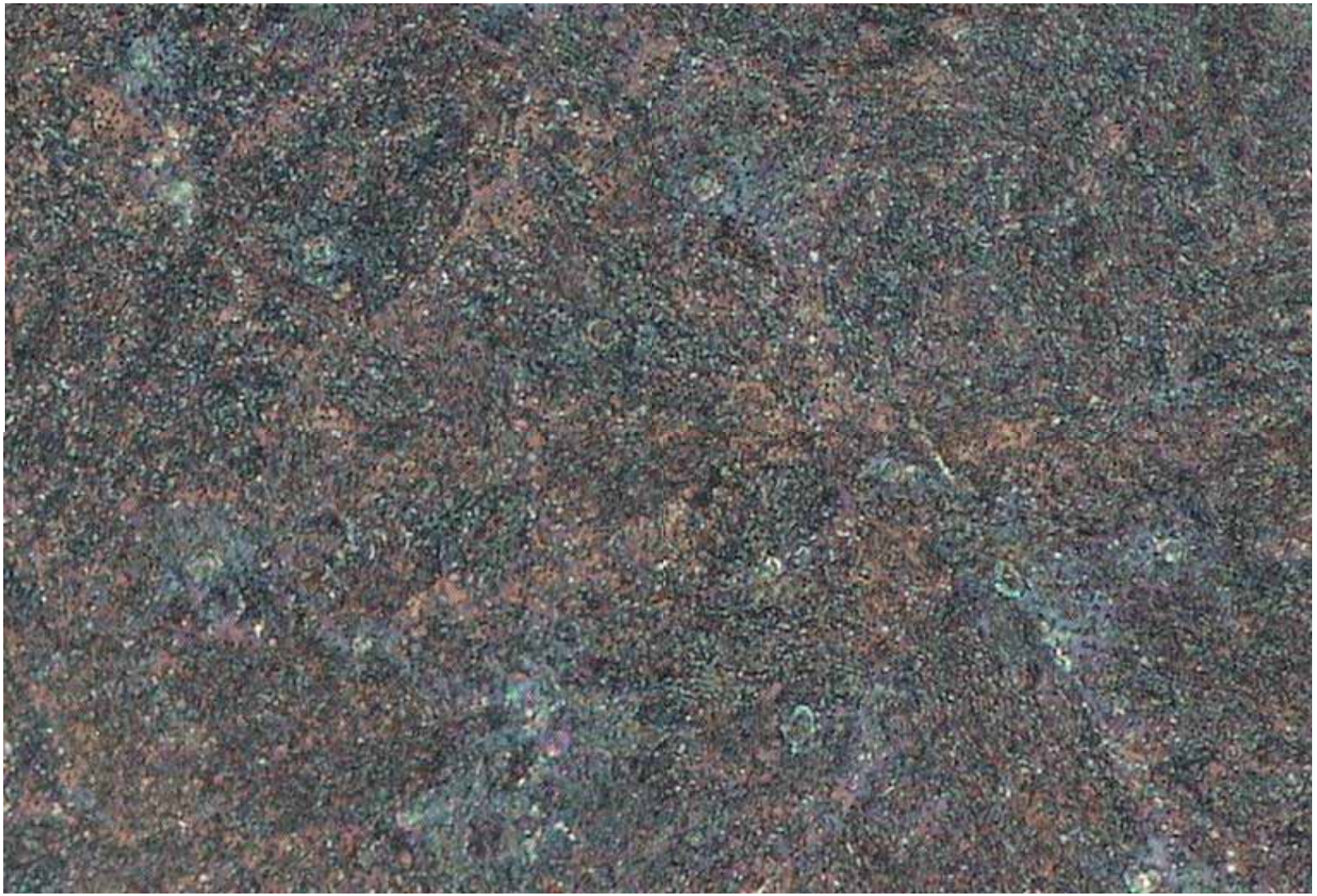


Photo.51: 500x, The microstrucutres are Pearlite and Ferrite. Fine bright particles are Carbides.

图51：
500x, 该显微结构为珠光体和铁素体。细亮颗粒为各种碳化物。

Record of Microstructures

Specimen No.: 15	Specimen name	Material	Condition
	Ferrous Metal	Gray Cast Iron	As cast, un-etched

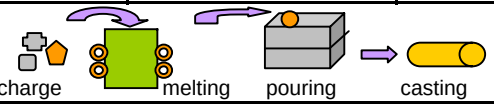
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	2.50-4.00	1.00-3.00	0.20-1.00	0.002-1.00	0.02-0.25	-	-	-	-	-	-	-	-

Similar steels	USA		Germany	FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN 1691	AFNOR NF A32101	GOST1412	GB 699	SS14	JIS	UNI5007	AS1830	BS 1452
	-	A48: 25	GG15	FGL200G	SCh18	-	0115.00	FC25	G15	T180	180

Characteristics and applications: Cast irons are alloys of iron(Fe), carbon©, and silicon(Si) in which more carbon is present than can be retained in in solid solution in austenite at the uetectic 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	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	885-925	790-900	755-790	250-650	Carbonitriding of gray cast iron is not recommended	-	Nitriding is not recom-mended.
	Soaking time, min.	1hr./25 mm.+1 hr.	1hr./25 mm.+1 hr.	1hr./25 mm.+1 hr.	2 hrs min.			
	Quenching medium	air or nitrogen	furnace cool	oil or water	air or faster			
	Hardness	163-217 HB	160-180 HB	45-50 HRC	48-22 HRC			

Manufacturing process of this specimen



Process: 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 dicharged 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.

Microstructures

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

图52：
100x, 灰铸铁，未经侵蚀，所示为石墨片的分布情形。

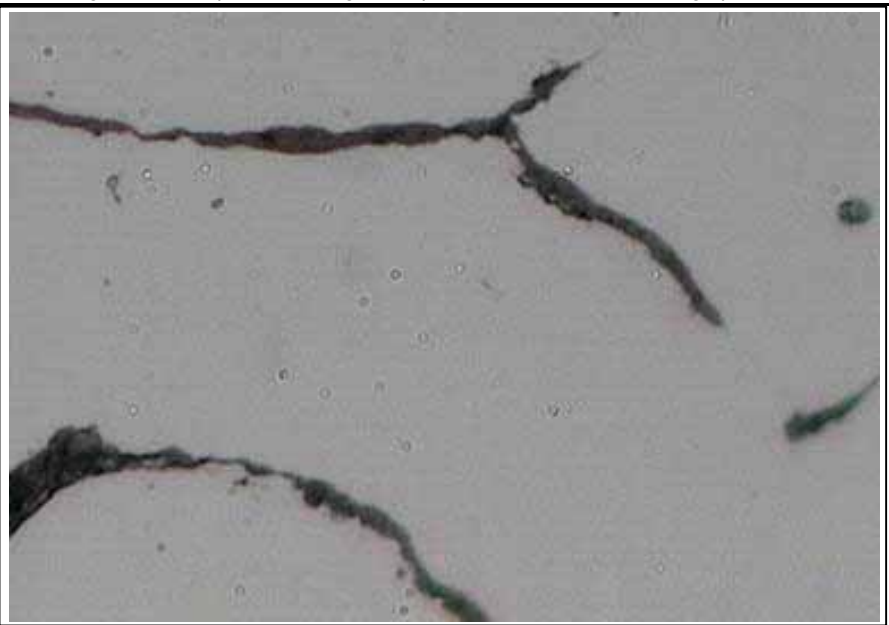


Photo.53:1000x, Same as in Photo.52, but in higher magnification, the dark gray scripts are graphite flakes.

图53：
1000x，与图52相同，但放大倍数更高。暗灰迹为石墨片。

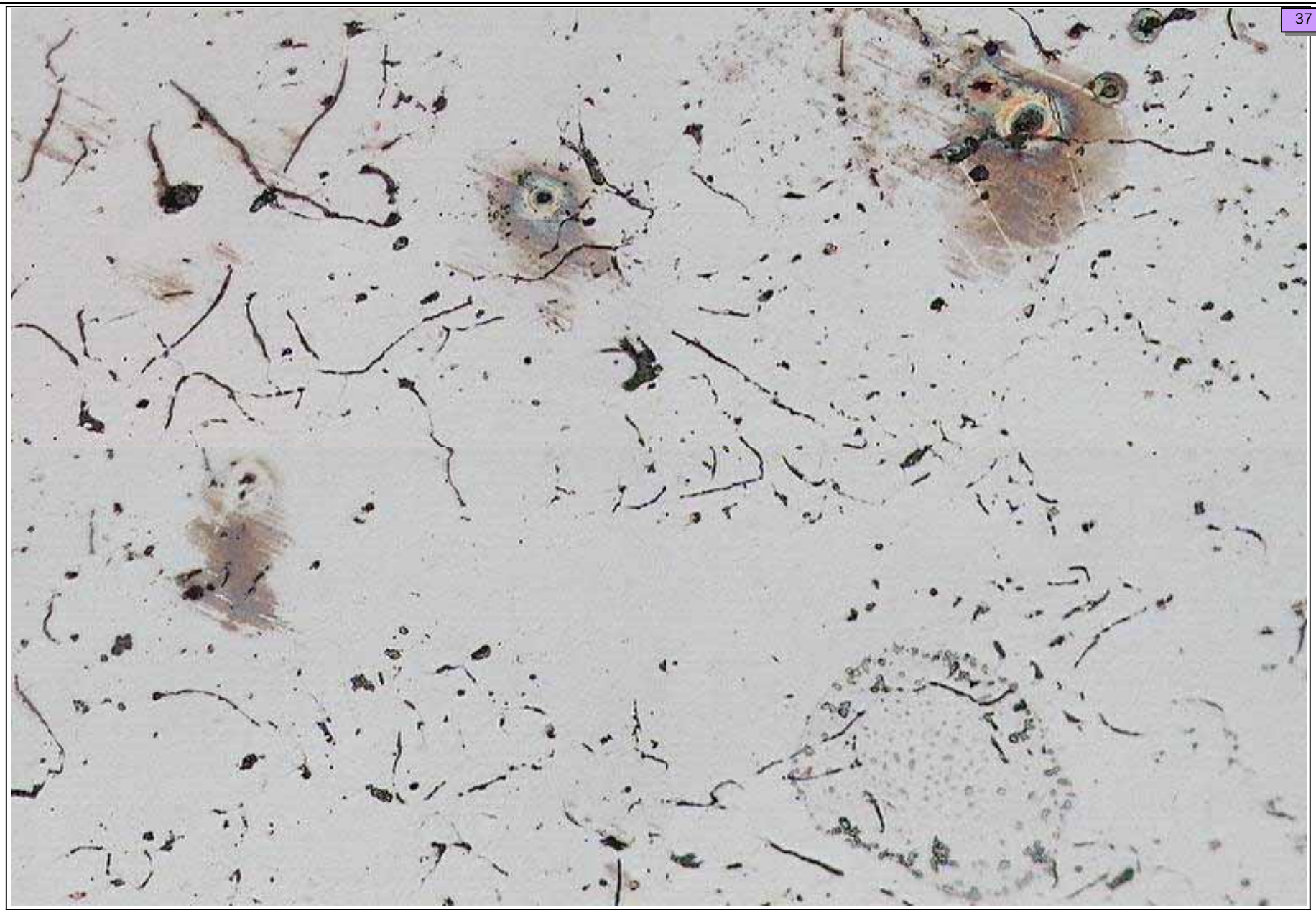


Photo.54: 200x, Showing graphite flake distribution and orientation. Dark gray particles and scripts are graphite flakkes. The matrix is un-revealed.

图54： 200x，所示为石墨片的分布情况及其方位。暗灰颗粒及暗灰迹为石墨片。

Record of Microstructures

Specimen No.: 16	Specimen name	Material	Condition
	Ferrous Metal	Gray Cast Iron	As cast, etched

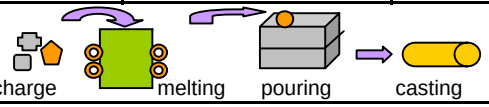
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	2.50-4.00	1.00-3.00	0.20-1.00	0.002-1.00	0.02-0.25	-	-	-	-	-	-	-	-

Similar steels	USA		Germany	FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN 1691	AFNOR NF A32101	GOST1412	GB 699	SS14	JIS	UNI5007	AS1830	BS 1452
	-	A48: 25	GG15	FGL200G	SCh18	-	0115.00	FC25	G15	T180	180

Characteristics and applications: Cast irons are alloys of iron(Fe), carbon©, and silicon(Si) in which more carbon is present than can be retained in in solid solution in austenite at the uetectic 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	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	885-925	790-900	755-790	250-650	Carbonitriding of gray cast iron is not recommended	-	Nitriding is not recom-mended.
	Soaking time, min.	1hr./25 mm.+1 hr.	1hr./25 mm.+1 hr.	1hr./25 mm.+1 hr.	2 hrs min.			
	Quenching medium	air or nitrogen	furnace cool	oil or water	air or faster			
	Hardness	163-217 HB	160-180 HB	45-50 HRC	48-22 HRC			

Manufacturing process of this specimen



Process: 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 dicharged 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

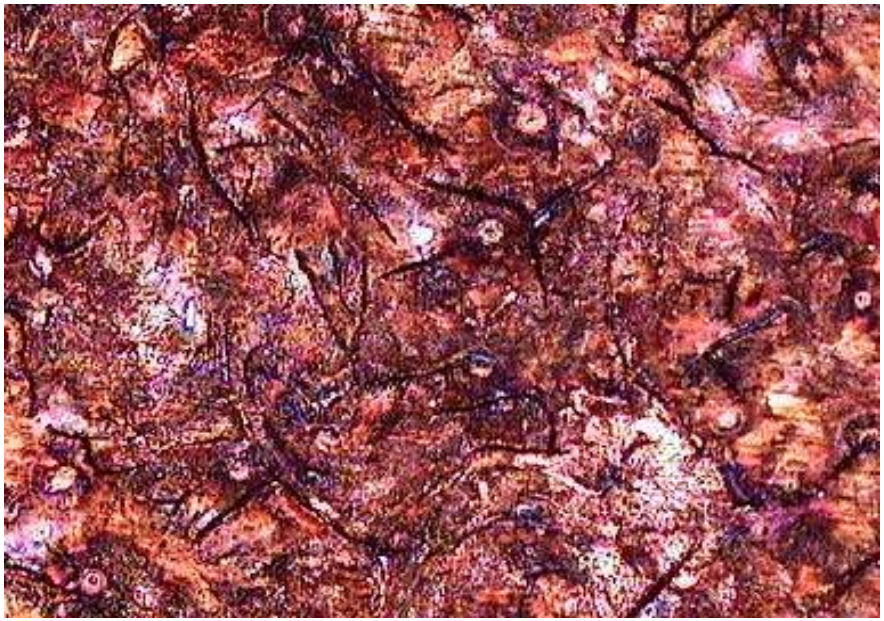


Photo.55:100x, Gray cast iron, as cast, etched, showing graphite and matrix.

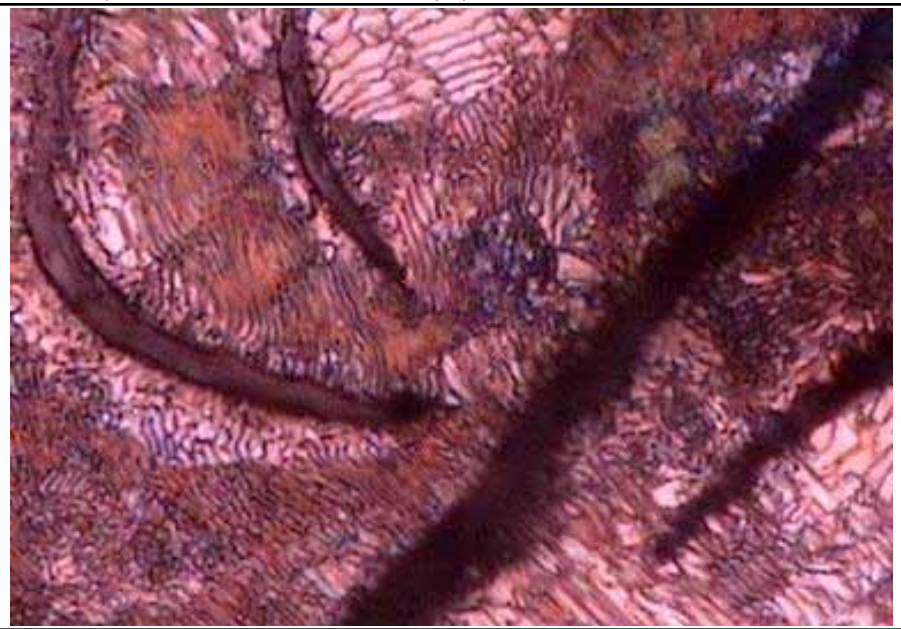


Photo.56:1000x, Same as in Photo.55, but in higher magnification, dark scripts are graphite flakes, matrix are Pearlite and Ferrite.

图55：
100x，灰铸铁，经铸造、侵蚀，所示为石墨及基体。

图56： 1000x，与图55相同，但放大倍数更高。暗色迹为石墨片，基体为珠光体和铁素体。

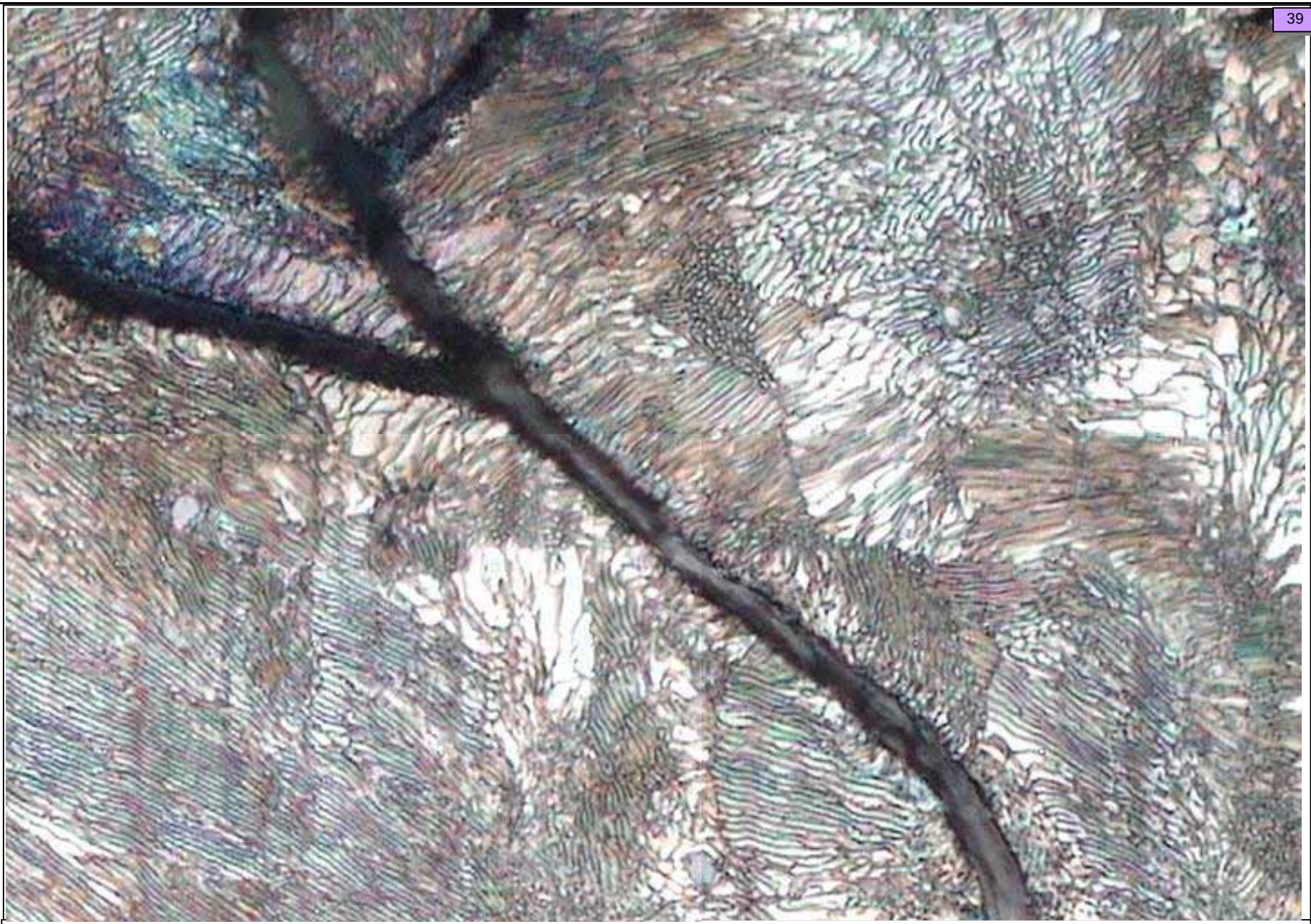


Photo.57:Same as in photo.56, but in larger area. Dark gray branches are graphite flakes. The matrix consists of Pearlite(small lines of cementite and Ferrite), and Ferrite.

图57：
与图56相同，但面积更大。暗灰分叉为石墨片。基体包含珠光体（细线为渗碳体和铁素体）和铁素体。

Record of Microstructures

Specimen No.: 17	Specimen name	Material	Condition
	Ferrous Metal	Gray Cast Iron	Hardened by quenching and tempering

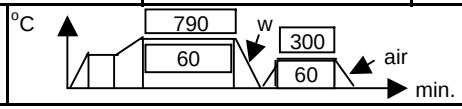
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	2.50-4.00	1.00-3.00	0.20-1.00	0.002-1.00	0.02-0.25	-	-	-	-	-	-	-	-

Similar steels	USA		Germany	FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	AUSTRALIA	UK
	AISI/SAE	ASTM	DIN 1691	AFNOR NF A32101	GOST1412	GB 699	SS14	JIS	UNI5007	AS1830	BS 1452
	-	A48: 25	GG15	FGL200G	SCh18	-	0115.00	FC25	G15	T180	180

Characteristics and applications: Cast irons are alloys of iron(Fe), carbon©, and silicon(Si) in which more carbon is present than can be retained in in solid solution in austenite at the uetectic 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	Descriptions \ Processes	Normalizing	Annealing	Full hardening	Tempering	Carbonitriding	Tempering	Nitriding
	Temperature, °C	885-925	790-900	755-790	250-650	Carbonitriding of gray cast iron is not recommended	-	Nitriding is not recom-mended.
	Soaking time, min.	1hr./25 mm.+1 hr.	1hr./25 mm.+1 hr.	1hr./25 mm.+1 hr.	2 hrs min.			
	Quenching medium	air or nitrogen	furnace cool	oil or water	air or faster			
	Hardness	163-217 HB	160-180 HB	45-50 HRC	48-22 HRC			

Final processes of this specimen



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.

Microstructures

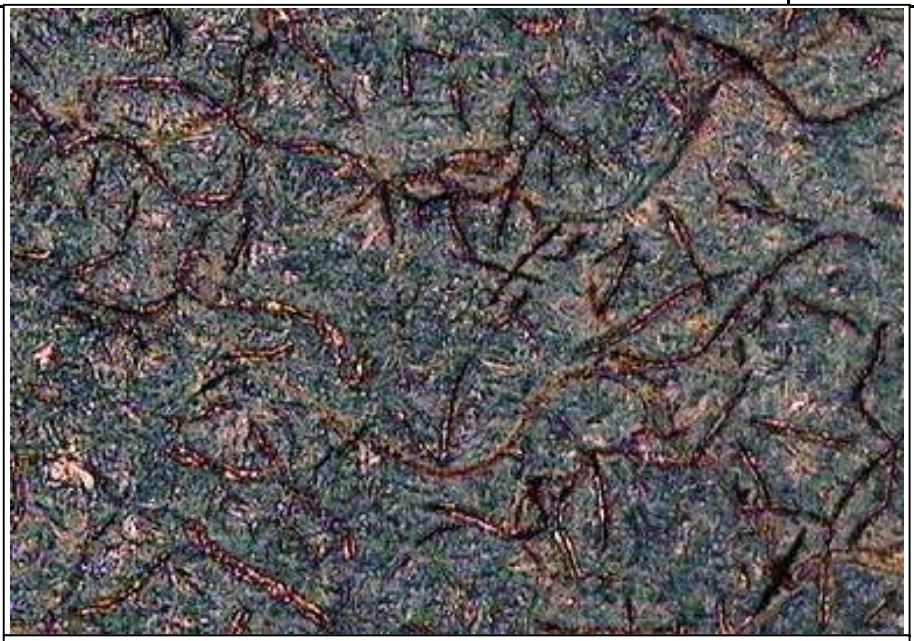


Photo.58:100x, Gray cast iron, quenched and tempered. The matrix is Martensite. Graphite flakes still remain.

图58：
100x, 灰铸铁，经淬火和回火处理。基体为马氏体。石墨片仍然存在。

Photo.59:1000x, Same as in Photo.58, but in higher magnification. The matrix are Martensite. Gray area are graphite flakes.

图59：1000x，与图58相同，但放大倍数更高。其基体是马氏体。灰色区域为石墨片。

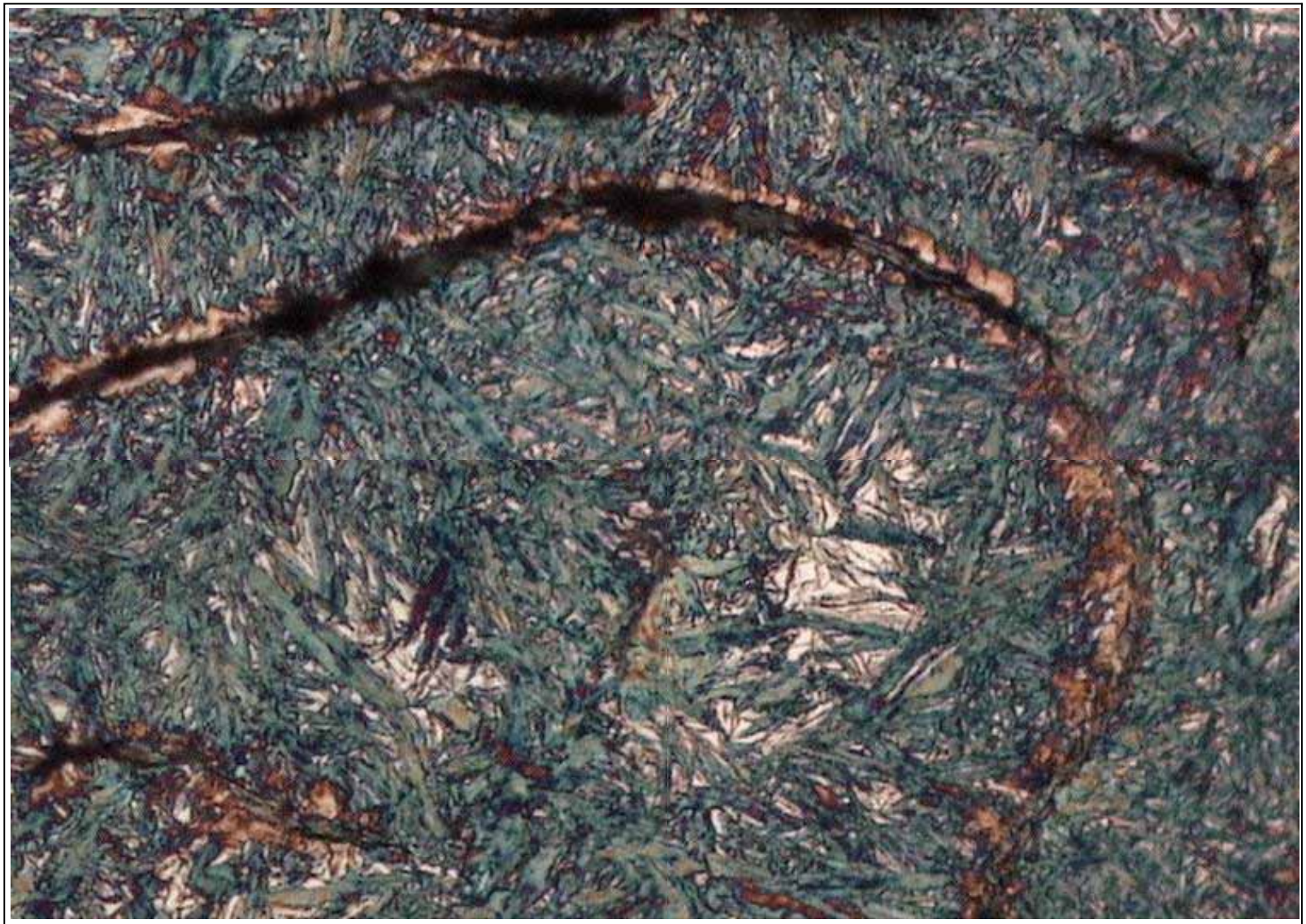


Photo.60:1000x, Acicular structures are Martensite, dark gray scripts are graphite flakes, and the yellow and light brown surrounded the grapgite flakes are Ferrite.

图60：
1000x，针状结构为马氏体，暗灰迹为石墨片，石墨片周围的黄色和浅棕色为铁素体。

Record of Microstructures

Specimen No.: 18	Specimen name	Material	Condition
	Ferrous Metal	White Cast Iron	As cast, etched

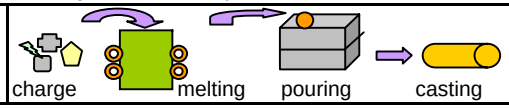
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	1.80-3.60	0.50-1.90	0.25-0.80	0.06-0.20	0.06-0.20	-	-	-	-	-	-	-	-

Similar steels	USA	Germany	FRANCE	RUSSIA	CHINA	SWEDEN	JAPAN	ITALY	INDIA	UK
	AISI/SAE	DIN 1695	AFNOR NF A32-401	-	-	-		-	IS7925	BS 4844
	-	G-X300NiMo3Mg	FBO	-	-	-		-	1	1A

Characteristics and applications: Exhibits a white, crystalline fracture surface because fracture occures along the iron carbide plates; it is the result of metastable solidification(Fe_3C 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, soking 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



Process: 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.

Microstructures

Photo.61:100x, White cast iron(hypo-eutectic cast iron), as cast, microstructures consist of Pearlite(brown and dark brown area), and Ledeburite(eutectic:Cementite and Pearlite).

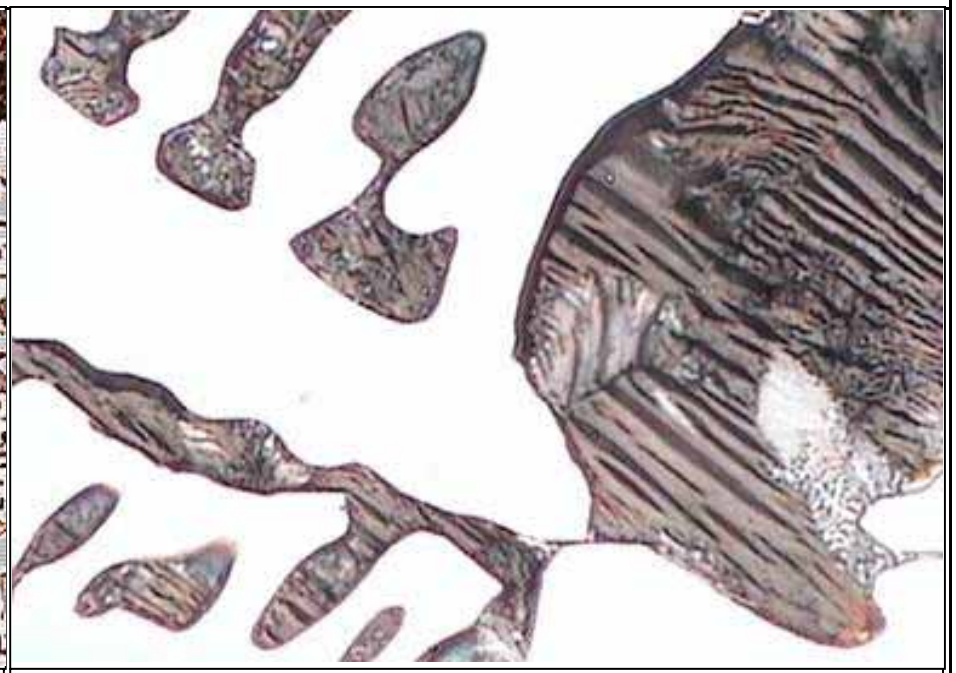


Photo.62:1000x, Same as in Photo.61, but in higher magnification. Large brown islands are free Pearlite which transformed from primary Austenite, small islands are Pearlite, parts of Ledeburite(eutectic). Bright area are cementite(Fe_3C), parts of Ledeburite.

图61：
100x，白铸铁（亚共晶铸铁），经过铸造，该显微结构包含珠光体（棕色和暗棕色区域）和莱氏体（共晶：渗碳体和珠光体）。

1000x，与图61相同，但放大倍数更高。大块棕色岛状物是由初始奥氏体转化而来的游离珠光体。小块岛状物是珠光体及部分莱氏体（共晶）。亮色区域为渗碳体（Fe3C）及部分莱氏体。

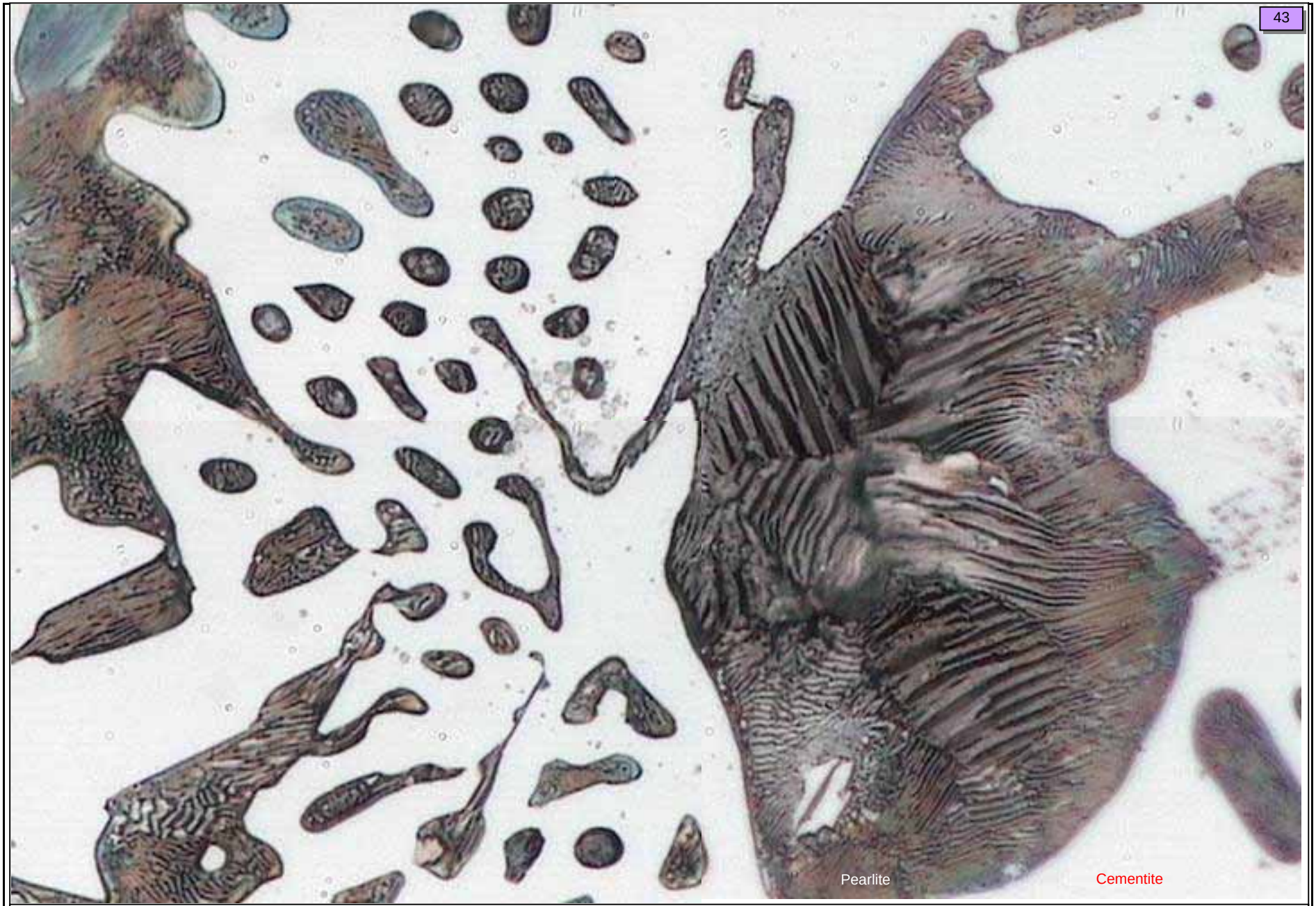


Photo.63:1000x, Same as in Photo.62, but in larger area, showing Pearlite, and Ledeburite.

图63： Pearlite: 珠光体； Cementite:渗碳体
1000x，与图62相同，但面积更大。所示为珠光体和莱氏体。

Record of Microstructures

Specimen No.: 19	Specimen name	Material	Condition
	Ferrous Metal	Malleable iron(annealed white cast iron)	annealed

44

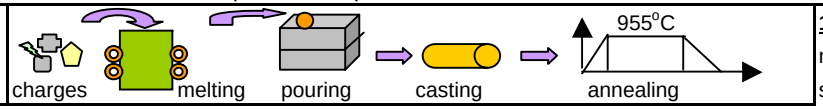
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	2.20-2.90	0.90-1.90	0.15-1.20	0.02-0.20	0.02-0.20	-	-	-	-	-	-	-	-

Similar steels	USA	INTERNATIONAL	FRANCE	RUSSIA	NETHERLANDS	JAPAN	ITALY	INDIA	UK
	ASTM A220	ISO5922	AFNOR NF A32-702	GOST1215	NEN 6002-C	JIS G5704	-	IS2640	BS 6681
	45006	P45-06	MN450-6	KCh45-7	GSMp45	FCMP45	-	PM440	P45-06

Characteristics and applications: Malleable 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: Malleble iron can be hardened by the following methods: 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 reaustenize the matrix and homogenize the combined carbon; and then quench in heated(50°-65°) 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, weighrd 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 740oC 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

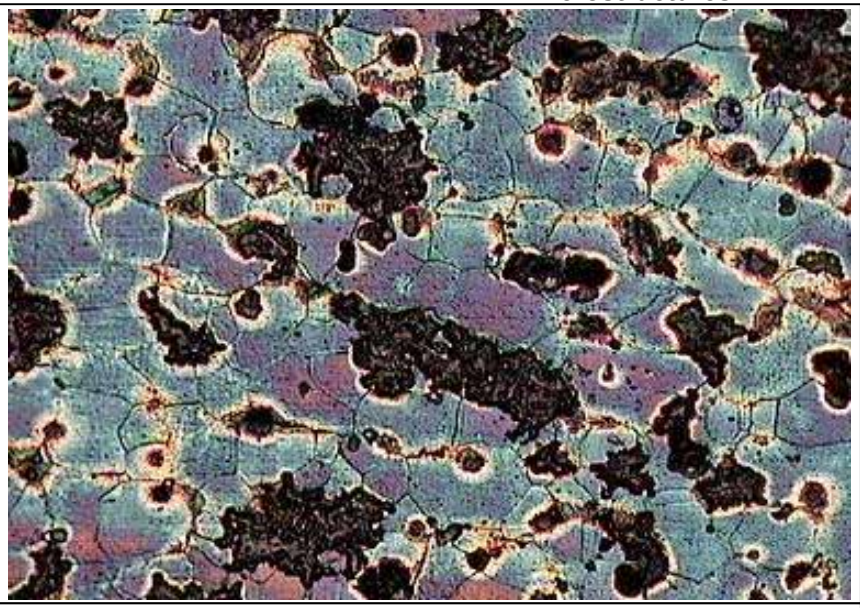


Photo.64:100x,Dark gray islands are tempered graphites. Purple and blue-green area are Ferrite.

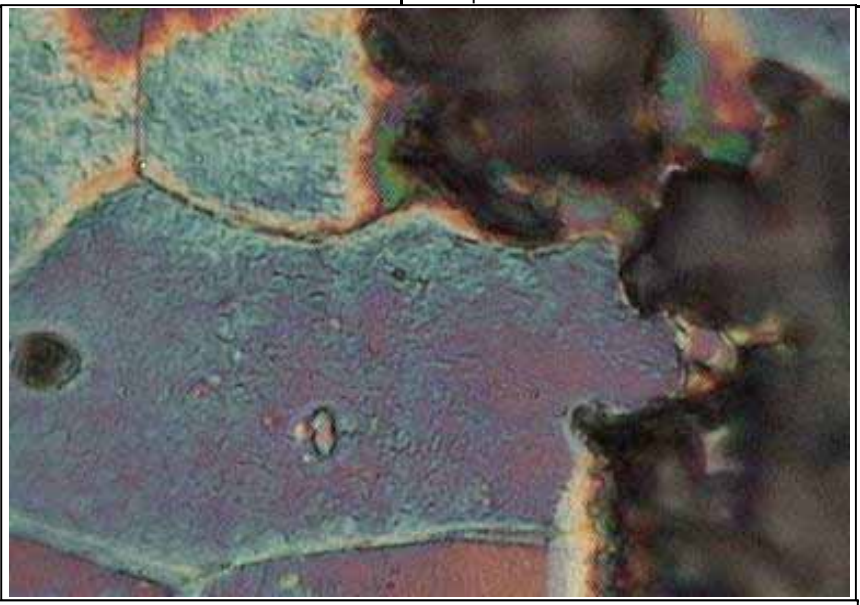


Photo.65:1000x, Same as in Photo.64, but in higher magnification. Dark gray islands are tempered graphite. The matrix is Ferrite.

图64：
100x，暗灰岛状物是经过回火处理的石墨。紫色和蓝绿色区域为铁素体。

图65：
1000x，与图64相同，但放大倍数更高。暗灰岛状物是经过回火处理的石墨。基体是铁素体。

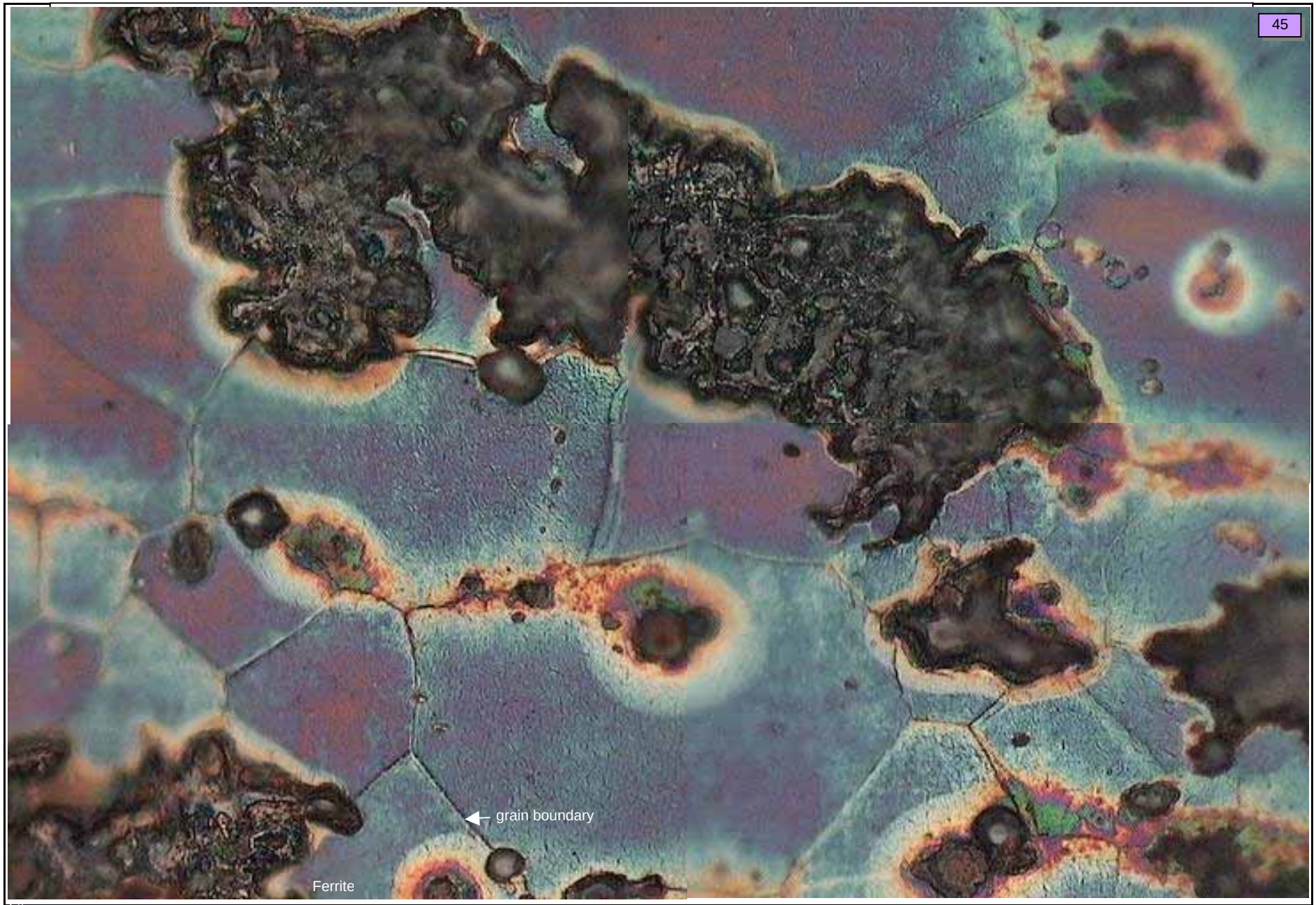


Photo.66:500x, Same as in Photo.65, but in larger area. Dark gray islands are tempered graphite. Purple and blue-green area are Ferrite.

图66： grain boundary: 晶粒间界 Ferrite:铁素体
500x, 与图65相同，但面积更大。暗灰岛状物是经过回火处理的石墨。紫色和蓝绿色区域是铁素体。

Record of Microstructures

Specimen No.: 20	Specimen name	Material	Condition
	Ferrous Metal	Nodular Cast Iron	Annealed, un-etched

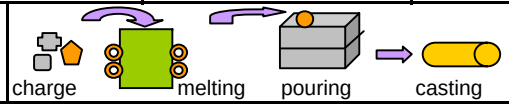
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	3.000-4.00	1.80-2.80	0.10-1.00	0.01-0.10	0.01-0.03	-	-	-	-	-	-	-	-

Similar steels	USA	Germany	FRANCE	RUSSIA	SWEDEN	JAPAN	INTERNATIONAL	UK
	ASTM A536-84	DIN 1693	AFNOR NF A32201	GOST7293	SIS 1407	JIS G5502	ISO 1083	BS 72892
	60-42-10	GGG45	FGS450-10	VCh45	0722-00	FCD45	450-10	450/10

Characteristics and applications: Nodular cast iron can be called Ductile cast iro 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, compreesor crankshafts, joints, etc.

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

Manufacturing process of this specimen



Process: 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 ditribution.

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.

图67：
100x、球墨铸铁、未经侵蚀、所示为球状石墨（暗棕色颗粒）。

图68： graphite: 石墨； matrix: 基体
1000x, 与图67相同，但放大倍数更高。暗灰岛状物是球状石墨。

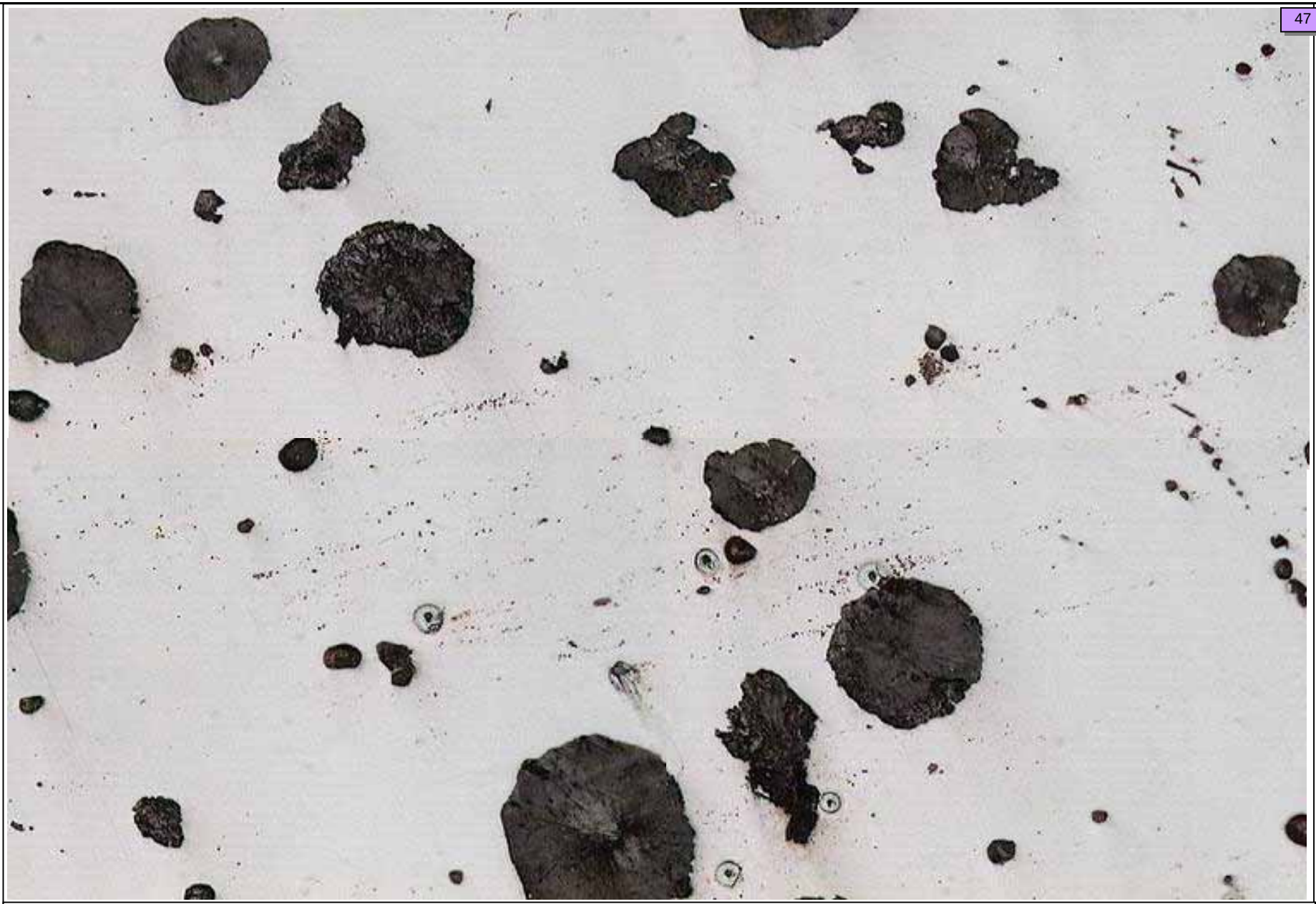


Photo.69:200x, Round particles are spheroidal graphites. The matrix can not be revealed in unetched condition.

图69：
200x，圆形颗粒是球状石墨。基体在未侵蚀条件下无法呈现出来。

Record of Microstructures

Specimen No.: 21	Specimen name	Material	Condition
	Ferrous Metal	Nodular Cast Iron	Annealed, etched

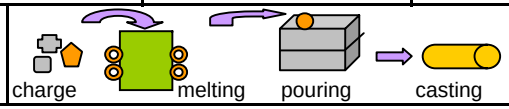
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	3.00-4.00	1.80-2.80	0.10-1.00	0.01-0.10	0.01-0.03	-	-	-	-	-	-	-	-

Similar steels	USA	Germany	FRANCE	RUSSIA	SWEDEN	JAPAN	INTERNATIONAL	UK
	ASTM A536-84	DIN 1693	AFNOR NF A32201	GOST7293	SIS 1407	JIS G5502	ISO 1083	BS 72892
	60-42-10	GGG45	FGS450-10	VCh45	0722-00	FCD45	450-10	450/10

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, compreesor crankshafts, joints, etc.

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

Manufacturing process of this specimen



Process: 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 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).

图70： Ferrite: 铁素体；Pearlite: 珠光体；graphite: 石墨
100x， 球墨铸铁，经过侵蚀，棕色圆形颗粒是球状石墨。基体是铁素体（白色、紫色区域）和珠光体（棕色岛状物）。

Photo.71:1000x, Same as in Photo.70, but in higher magnification. Gray area is graphite. Purple and blue-green area are Ferrite.

图71： 1000x, 与图70相同，但放大倍数更高。灰色区域是石墨。紫色和蓝绿色区域是铁素体。

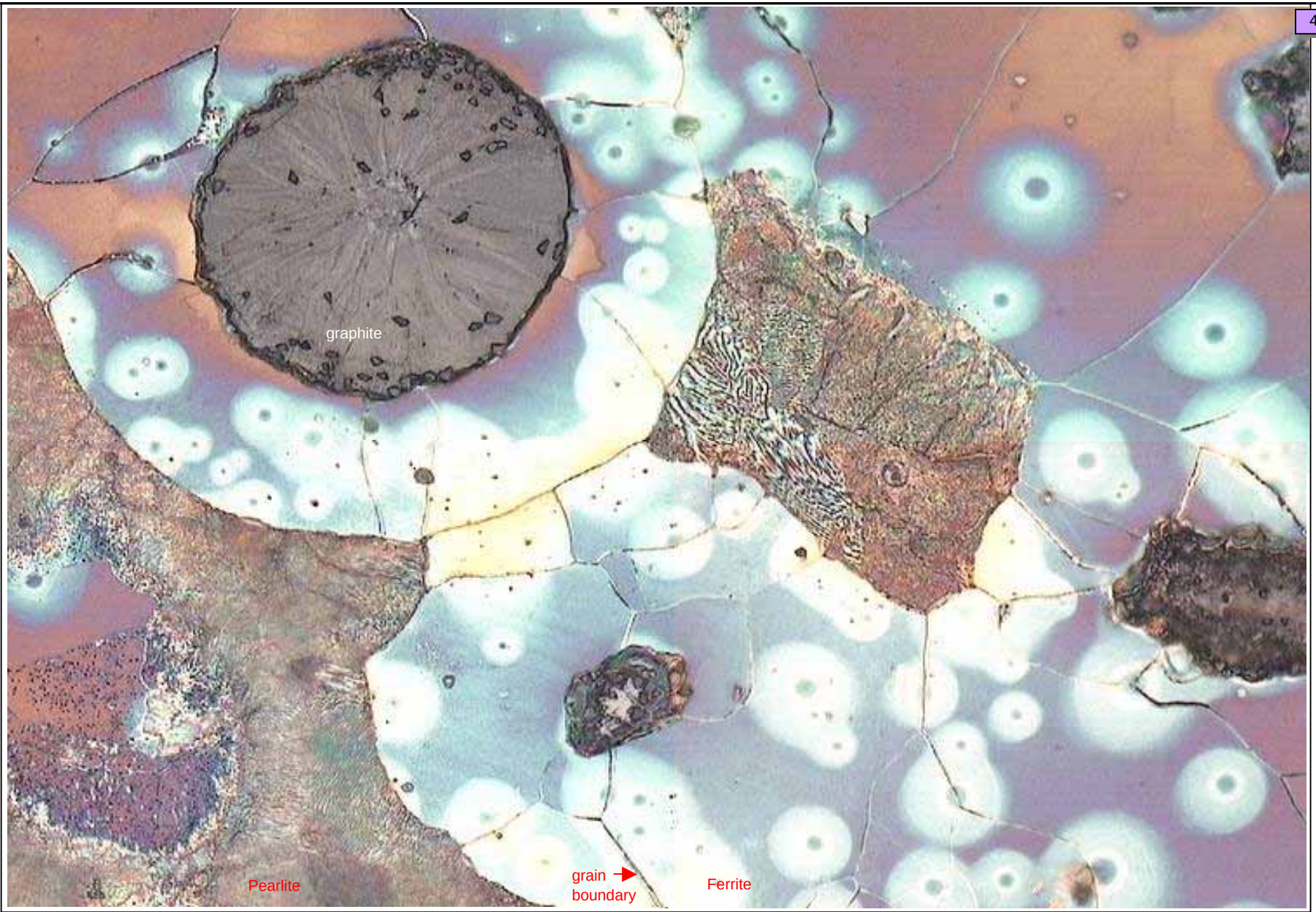


Photo.72:500x, Same as in Photo.71, but in larger area. The microstructures consist of spreroidal graphites, Pearlite and Ferrite. Bull's eyes structure can be seen in this Photo. (Bull's structure consists of graphit nodule in the center surrounded with Ferrite, and the outmost area is Pearlite. It looks like Bull's eyes.

图72： 500x，与图71相同，但面积更大。该显微结构包含球状石墨、珠光体和铁素体。本照片清晰可见牛眼结构。（牛眼结构由被铁素体包围在中心的石墨球及最边远的珠光体构成。这种结构看起来像牛眼）

Record of Microstructures

Specimen No.: 22	Specimen name	Material	Condition
	Ferrous Metal	Bainitic Ductile Iron(BDI)	as cast

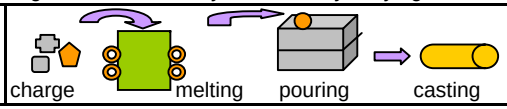
Chemical	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
composition	3.50	2.50	0.90	0.050	0.040	-	0.25	3.00	-	-	-	-	-

Similar grade of BDI: The common name of this special cast iron is Bainitic Ductile Iron or BDI. Most foundries are also produce this kind of cast iron under the name Bainitic Ductile or BDI.

Characteristics and applications: Bainitic Ductile Iron(BDI) is the 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 aalready hardened by alloying.

Manufacturing process of this specimen



Process: The charges (consist of pig iron, cast iron scraps, steel scraps, FeSi, FeMn, flux) were charged into induction furnace and melted into liquid metal, Ni, Mo, and inoculant were added during the process, the liquid metal was discharged into the crucible and then poured into the sand mould. The liquid metal will solidify as the casting then cut, mounted, ground, polished, and etched for the examination.

Microstructures

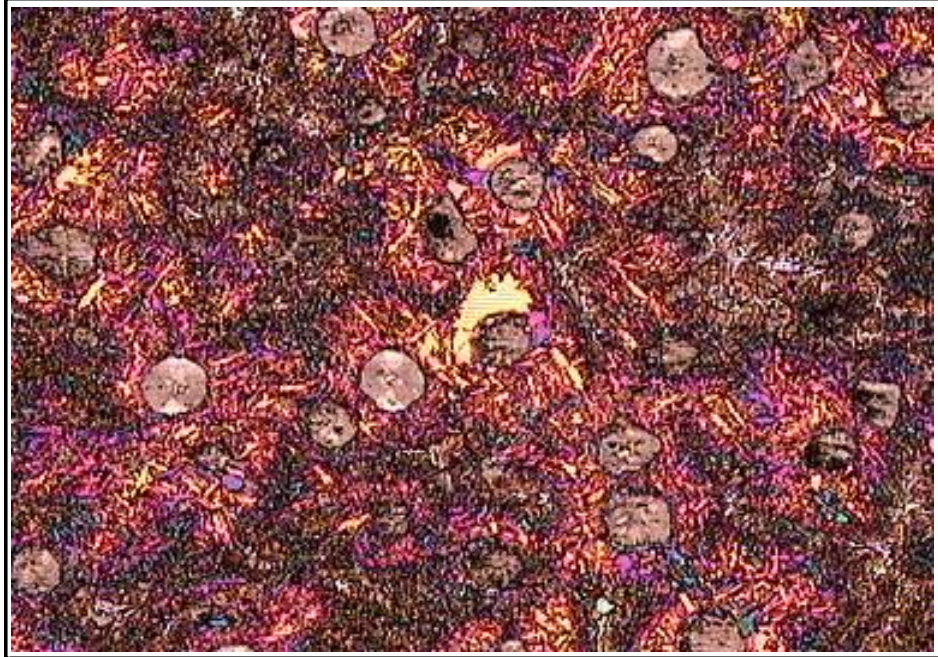


Photo.73,100x, Bainitic Ductile Iron(BDI), etched, showing Bainite matrix and sphreoidal graphite.

图73：
100x，贝氏体球铁（BDI），经过侵蚀，所示为贝氏体基体和球状石墨。

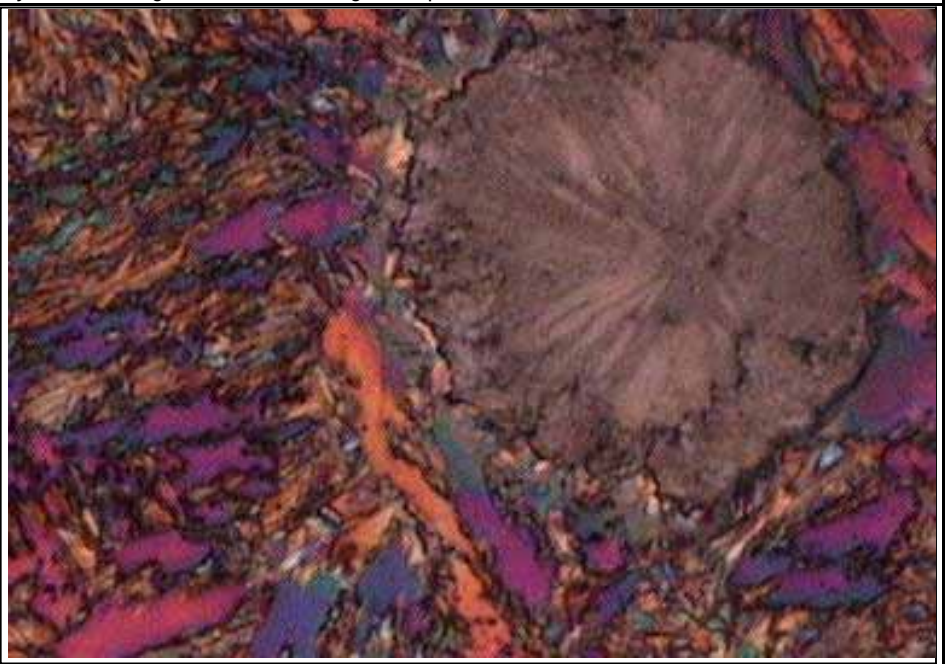


Photo.74:1000x, Same as in Photo.73, but in higher magnification. Brown round area is spheroidal graphite surrounded with Bainite(purple,orange, blue-green, and brown area).

图74：
1000x，与图73相同，但放大倍数更高。棕色圆形区域是被贝氏体（紫、橙、蓝绿及棕色区域）包围的球状石墨。

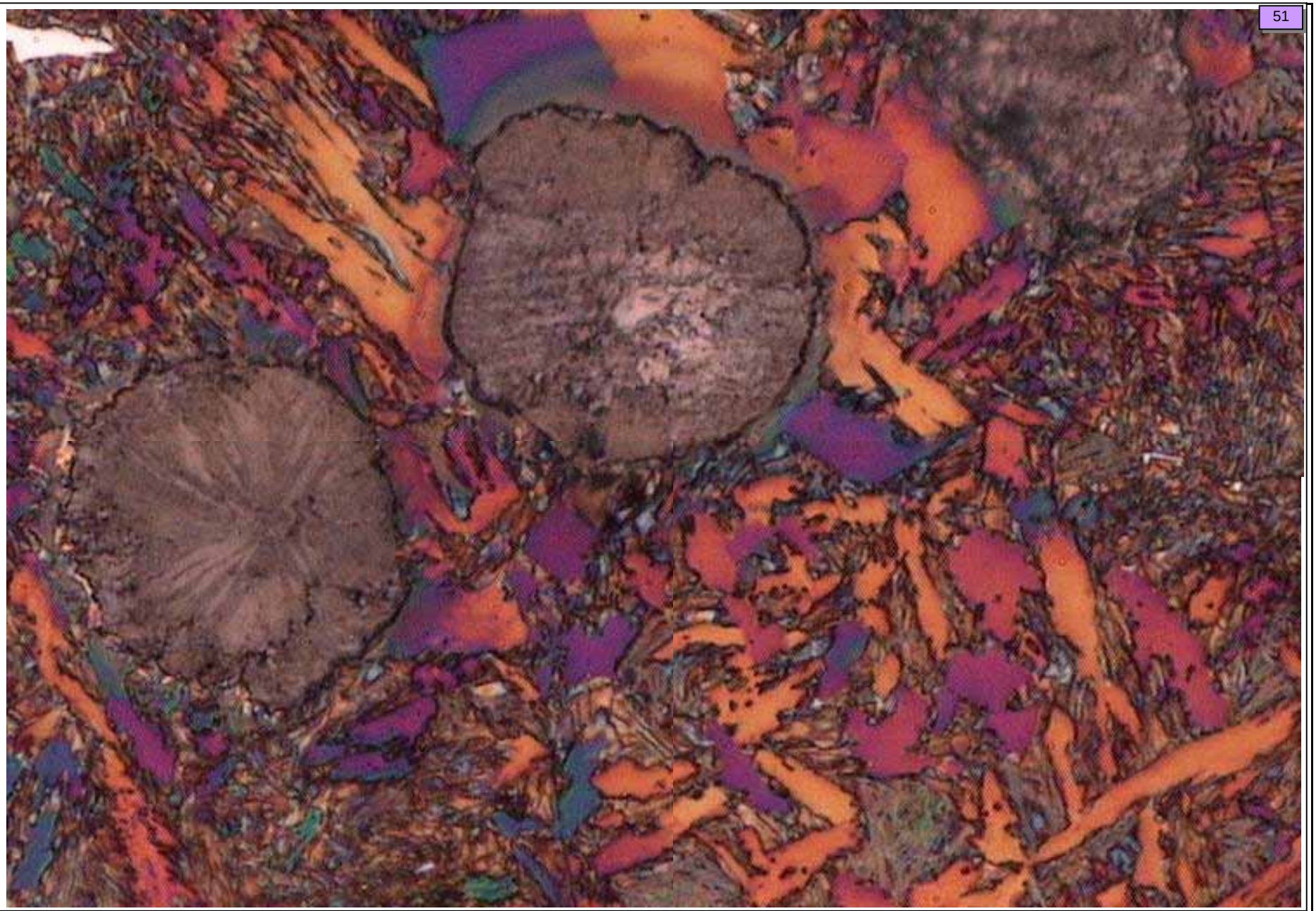


Photo.75:1000x, Same as in Photo.74, but in larger area. The microstructures consist of spheroidal graphites, and Bainite matrix. Some ferrite remained beside graphite.

图75： 1000x，与图74相同，但面积更大。该显微结构包含球状石墨及贝氏体基体。石墨旁还残留有某些铁素体。

Record of Microstructures

Specimen No.: 23	Specimen name	Material	Condition
	Ferrous Metal	Wear resistant cast iron	As cast

Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Ti	Co	W	Others
	2.00-3.30	1.50 max	2.00 max	0.10 max	0.06 max	23.00-30.00	3.00 max	2.50 max	1.20 max	-	-	-	-

Similar steels	USA	Germany	FRANCE	SWEDEN	INDIA	UK
	ASTM A532	DIN 1695	AFNOR NF A32-401	SIS 140466	IS 4771-3	BS 4844
	IIIA:25% Cr	G-X260Cr27; G-X300CrMo271	FBCr26MoNi	466	HCr27/400	3D

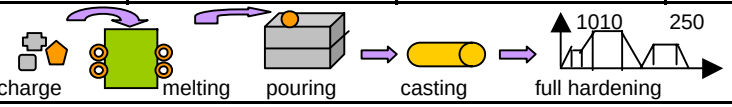
Characteristics and applications: This grade of cast iron is in the group of The high alloy white irons which are primarily used for abrasion-resistant applications and are readily cast in the shapes needed in the machinery used for crushing, griding, and general handling of abrasive materials. The eutectic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

Heat treatment guide

Descriptions \ Processes	Sub-zero treatment	Full hardening	Tempering
Temperature, °C	-80 to -196	1010-1020*	205 to 260
Soaking time, min.	60 min./25 mm. thickness	3 to 4 hours minimum.**	3 to 4 hours minimum.*
Quenching medium	air	air/oil	air
Hardness	-	-	-

Note:
* Heavy sections usually require higher temperatures within the range.
** For heavy sections the rule of 1 hour per 25 mm. thickness is usually adequate.

Manufacturing process of this specimen



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 molud and heated to 1010℃ and air cooled and tempered at 250℃.

Microstructures

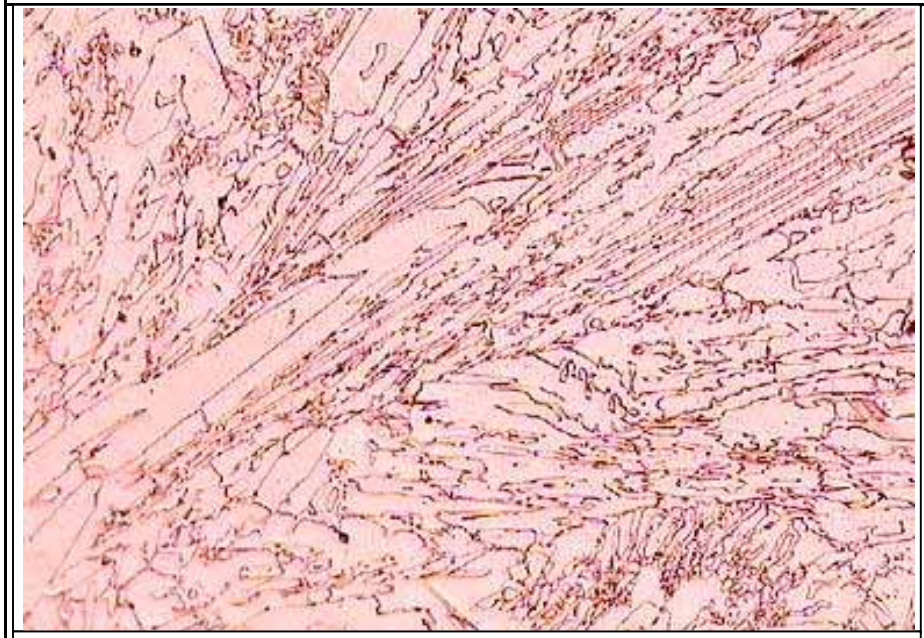


Photo.76:100x, Wear resistant cast iron, etched. The structures are chromium carbides.

图76：
100x, 耐磨铸铁，经过侵蚀。该结构为碳化铬。

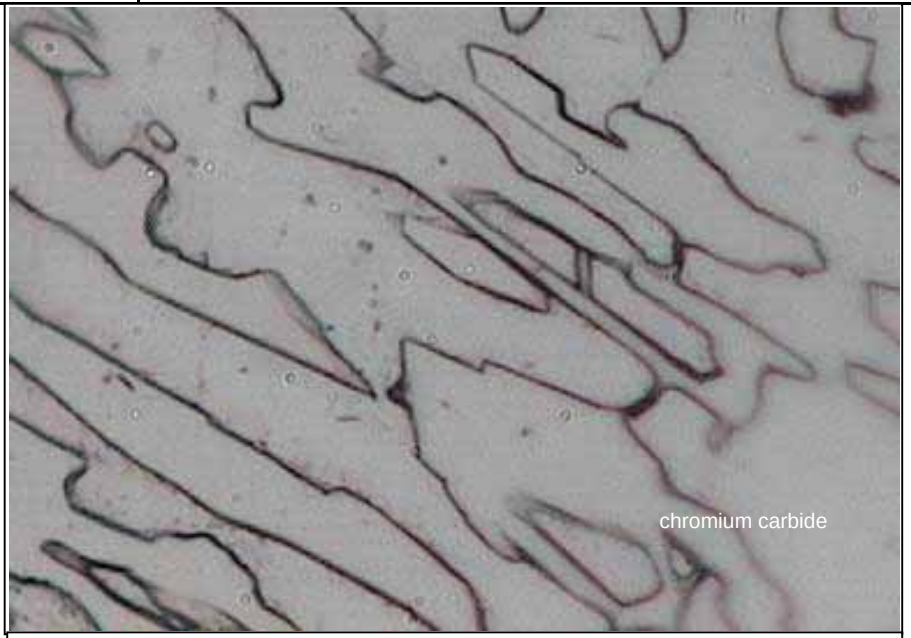


Photo.77:1000x, Same as in Photo.76, but in higher magnification.

图77：
1000x，与图76相同，但放大倍数更高。

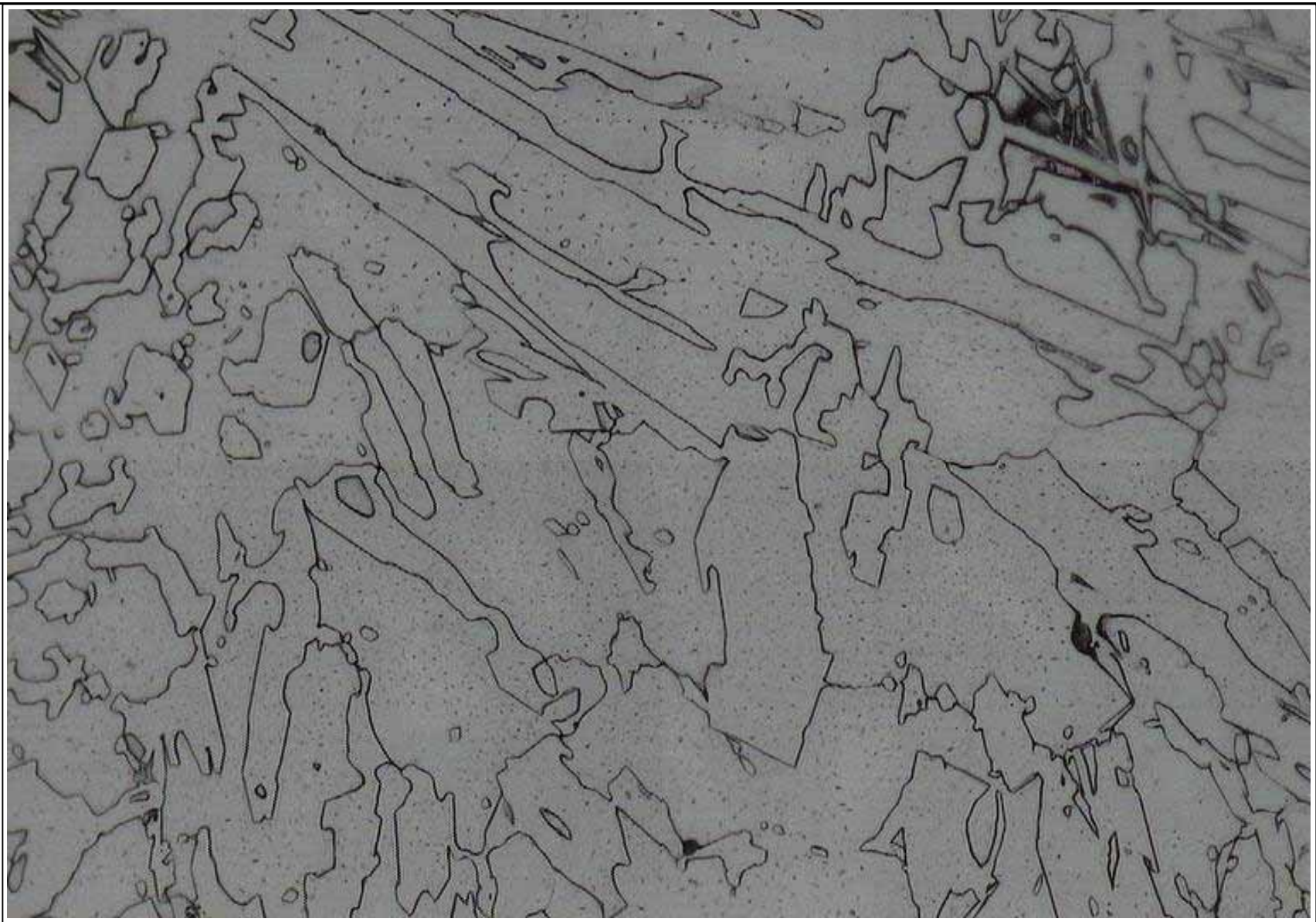


Photo.78:500x, Same as in Photo.77, but in larger area. The structures are chromium carbides.

图78：
500x，与图77相同，但面积更大。该结构为碳化铬。

Record of Microstructures

Specimen No.: 24	Specimen name	Material	Condition
	Ferrous Metal	High C-High Cr Tool steel(AISI D2)	Annealed

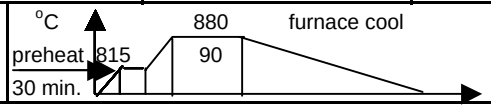
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	1.40-1.60	0.60 max	0.60 max	0.03	0.03	11.00-13.00	0.70-1.20	-	1.10 max	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	CHINA	SWEDEN	JAPAN	ITALY	INDIA	UK
	AISI/SAE	ASTM A681	DIN 17350	KRUPP	AFNOR NF A35-590	GB 1299	SIS14	JISG4404	UNI2955	IS 3749	BS 4659
	D2	D2	1.2379	2379	Z160CDV 12	3-2Cr12MoV	2310	SKD11	DCT-AR	T160Cr12	BD2

Characteristics and applications: Most available and most popular of the D series tool steels. Deep hardening, with low distorsion 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	Descriptions \ Processes	Normalizing	Annealing	Stress relieving	Hardening	Tempering	Nitriding
	Temperature, °C	Do not normalize	870 - 900	675-705	Pre:815;Aus:980-1025	205-540	500
	Soaking time, min.		90 min./inch of thickness	60 min./inch of thickness	15 min.(small);45 min.(large)	2 hrs min.	10-75 hrs.
	Quenching medium		furnace cool	air	air or nitrogen gas	air	furnace cool
	Hardness		217-255 HB	-	62 to 64 HRC	61- 54 HRC	>750 HV

Final heat treatment process of this specimen



Process: The specimen is heated to 880°C for 90 min., the steel microstructures will transform to austenite, 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

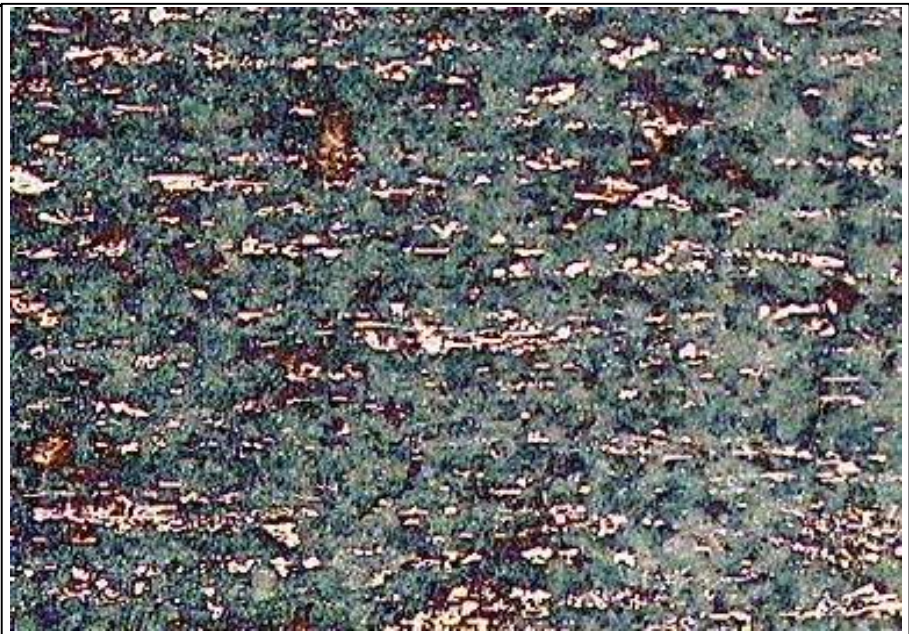


Photo.79:100x, AISI D2 Tool steel, annealed. Microstructures consist of Ferrite matrix and Carbides.

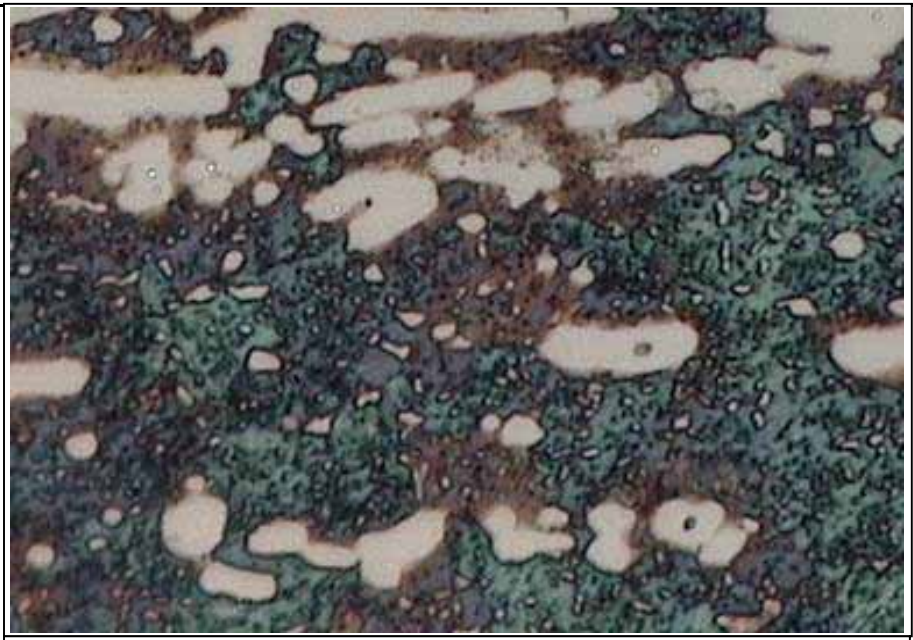


Photo.80:1000x, Same as in Photo.79, but in higher magnification. Ferrite matrix is colred greenand brown, Carbides remained bright particles.

图79： 100x，AISI D2 工具钢，经过退火处理。该显微结构包含铁素体基体和各种碳化物。

图80： 1000x，与图79相同，但放大倍数更高。彩色绿棕为铁素体基体，亮色颗粒为残留的各种碳化物。

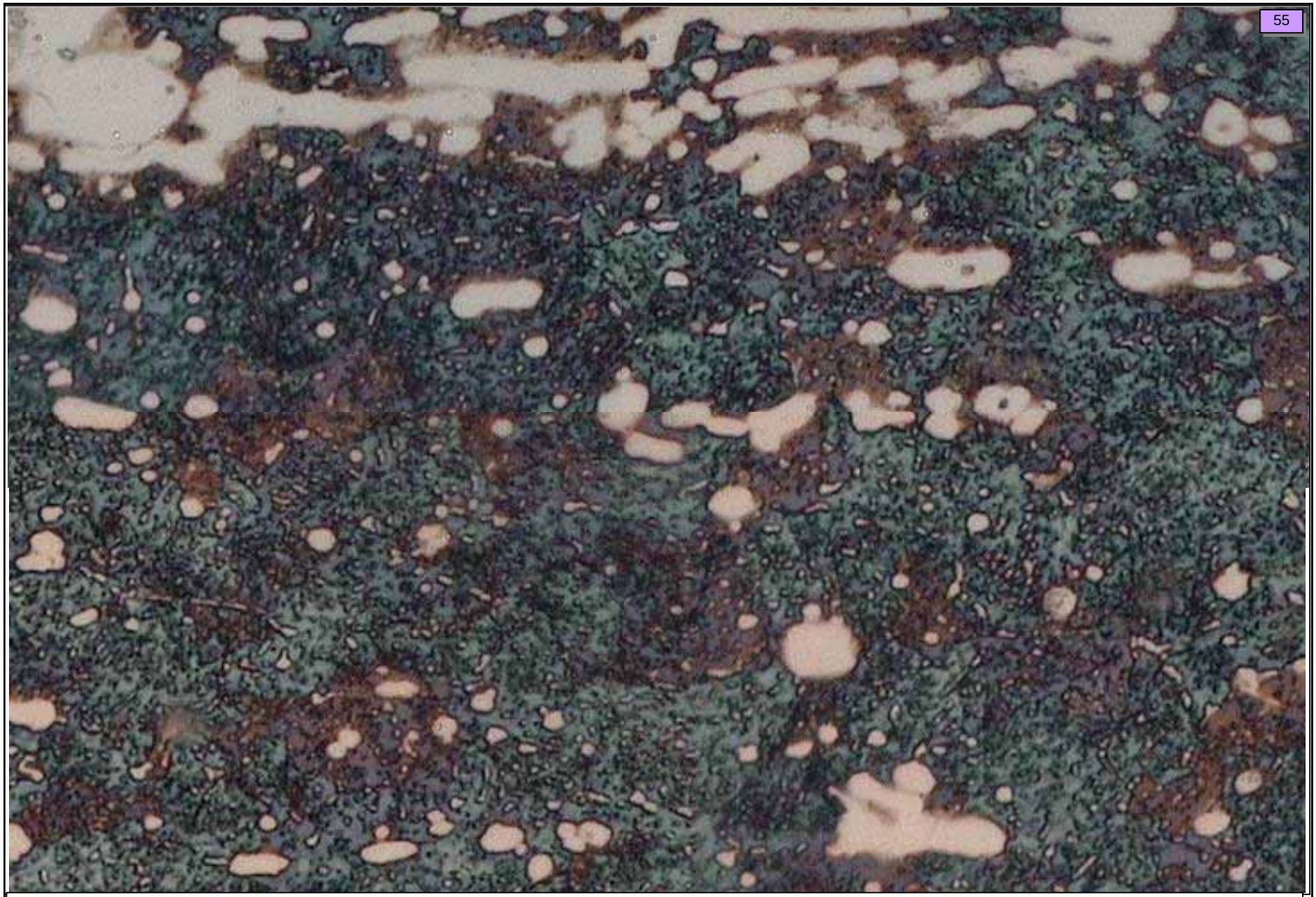


Photo.81:1000x, Same as in Photo.80, but in larger area, showing the distribution of Carbides in Ferrite matrix.

图81：
500x，与图80相同，但面积更大。所示为铁素体基体中各种碳化物的分布情况。

Record of Microstructures

Specimen No.: 25	Specimen name	Material	Condition
	Ferrous Metal	High C-High Cr Tool steel(AISI D2)	Quenched and tempered

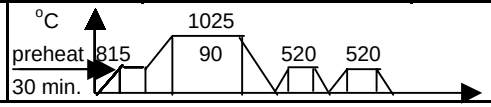
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	1.40-1.60	0.60 max	0.60 max	0.03	0.03	11.00-13.00	0.70-1.20	-	1.10 max	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	CHINA	SWEDEN	JAPAN	ITALY	INDIA	UK
	AISI/SAE	ASTM A681	DIN 17350	KRUPP	AFNOR NF A35-590	GB 1299	SIS14	JISG4404	UNI2955	IS 3749	BS 4659
	D2	D2	1.2379	2379	Z160CDV 12	3-2Cr12MoV	2310	SKD11	DCT-AR	T160Cr12	BD2

Characteristics and applications: Most available and most popular of the D series tool steels. Deep hardening, with low distorsion 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	Descriptions \ Processes	Normalizing	Annealing	Stress relieving	Hardening	Tempering	Nitriding
	Temperature, °C	Do not normalize	870 - 900	675-705	Pre:815;Aus:980-1025	205-540	500
	Soaking time, min.		90 min./inch of thickness	60 min./inch of thickness	15 min.(small);45 min.(large)	2 hrs min.	10-75 hrs.
	Quenching medium		furnace cool	air	air or nitrogen gas	air	furnace cool
	Hardness		217-255 HB	-	62 to 64 HRC	61- 54 HRC	>750 HV

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

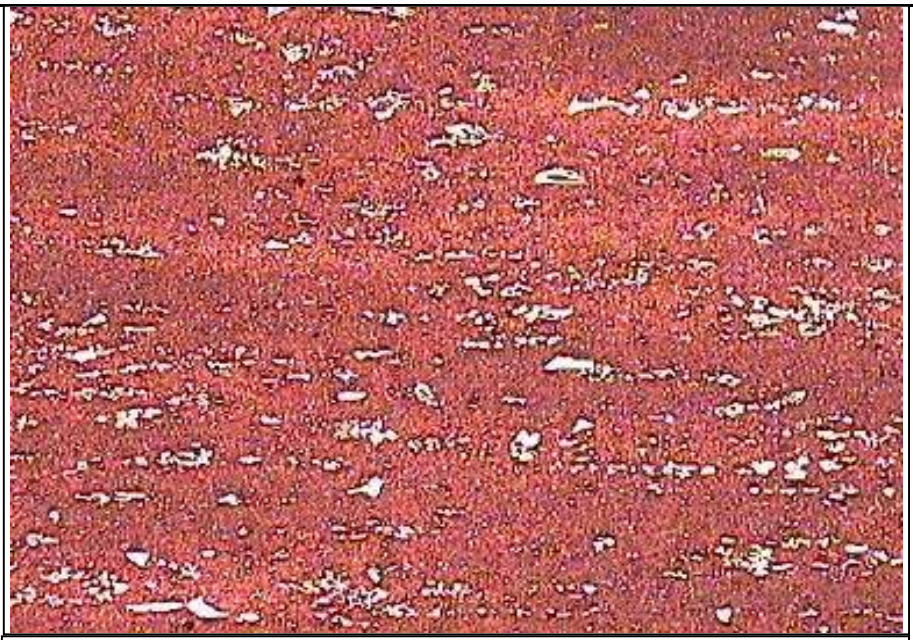


Photo.82:100x, AISI D2 Tool steel, quenched and tempered. Microstuctures consist of Martensite and Carbides.

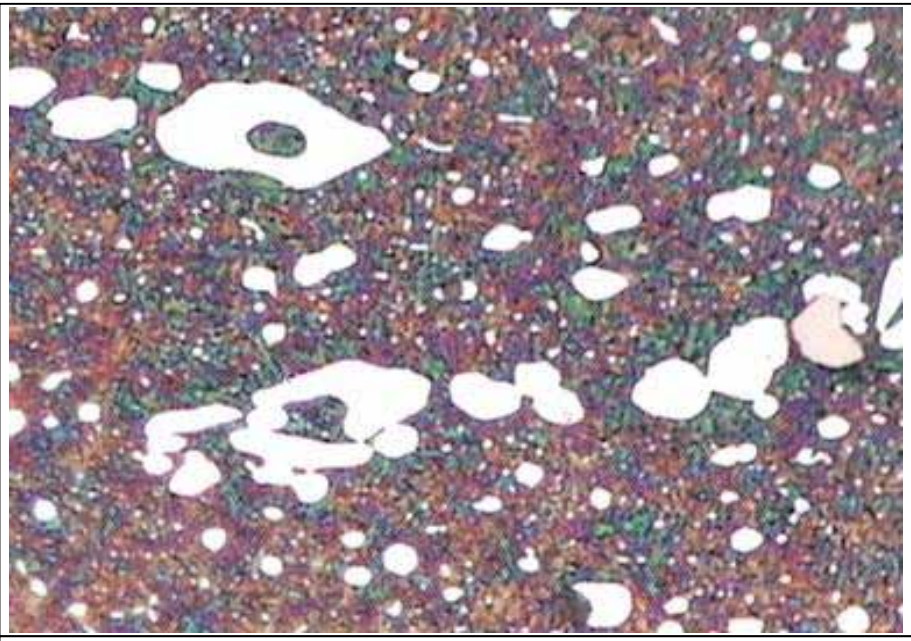


Photo.83:1000x, Same as in Photo.82, but in higher magnification. Martensite tinted variuos colors. Carbides remained bright particles.

图82： 100x，AISI D2工具钢，经过淬火、回火处理。该显微结构包括马氏体和各种碳化物。

图83： 1000x，与图82相同，但放大倍数更高。彩色部分为马氏体，亮色颗粒是残留的各种碳化物。

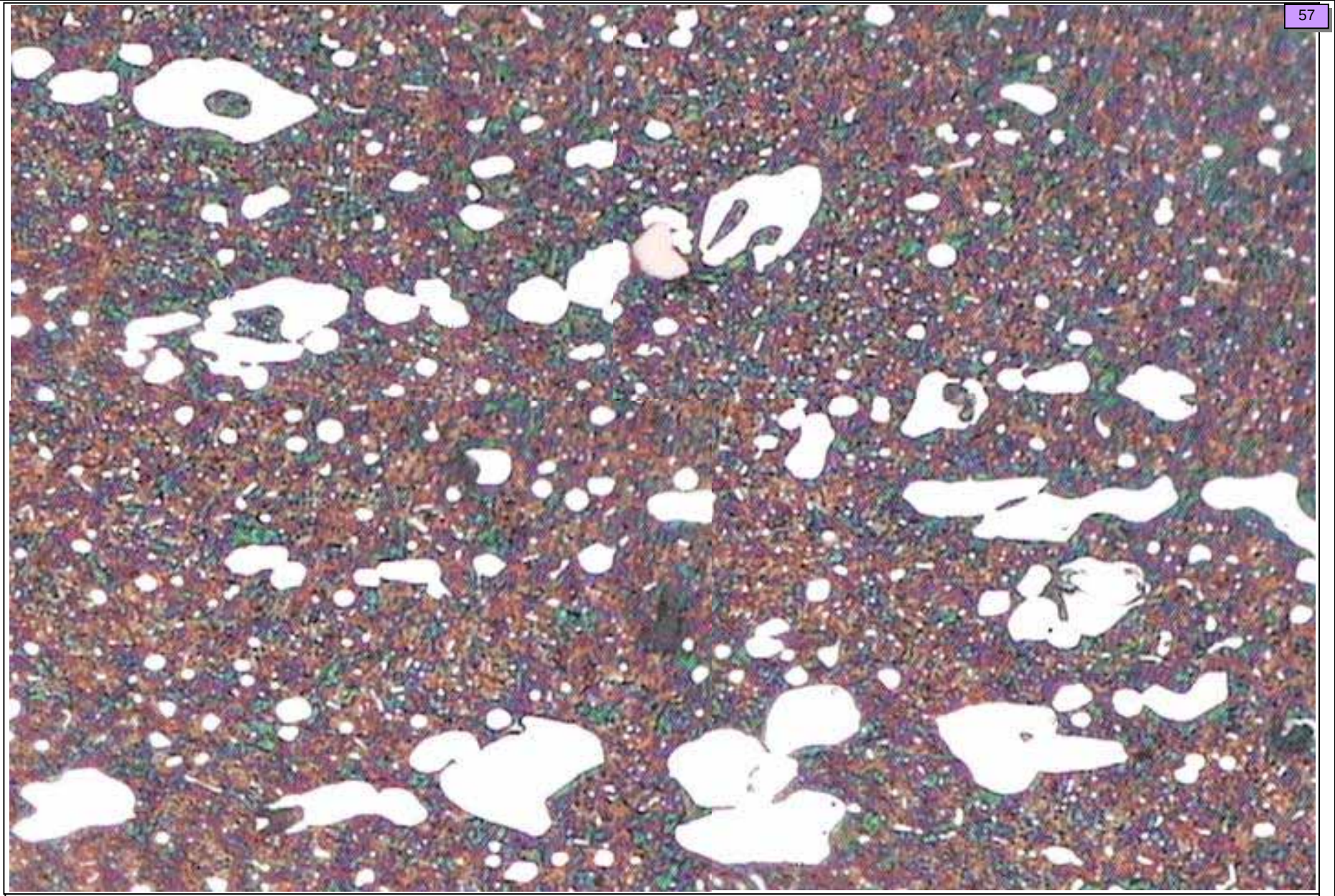


Photo.84:1000x, Same as in Photo.83, but in larger area. The matrix is Martensite tinted various colors, and bright particles are carbides.

图84：
1000x，与图83相同，但面积更大。彩色部分为马氏体，亮色颗粒为各种碳化物。

Record of Microstructures

Specimen No.: 26	Specimen name	Material	Condition
	Ferrous Metal	Mould tool steel (AISI P20)	Annealed

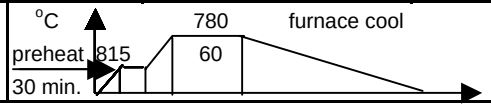
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.10 max	0.10-0.40	0.10-0.40	0.025 max	0.025 max	0.75-1.25	0.15-0.40	0.10-0.50	-	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	SWEDEN		JAPAN			RUSSIA	UK
	AISI/SAE	ASTM A681	DIN	KRUPP	AFNOR NF A35-590	SS14	ASSAB	DAIDO	HITACHI	N.KOSHUHA	GOST	BS4659
	P20	P20	1.2311	2311	35CM7D	USA P20	718Supreme	PX 4	YSS: HPM 2	Plasmold20	4ChS	USA P20

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 subsequench 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 immpression has been machined. Most application is for plastic mold making.

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

Final heat treatment process of this specimen



Process: The specimen is heated to 780°C for 60 min., the steel microstructures will transform to austenite, 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

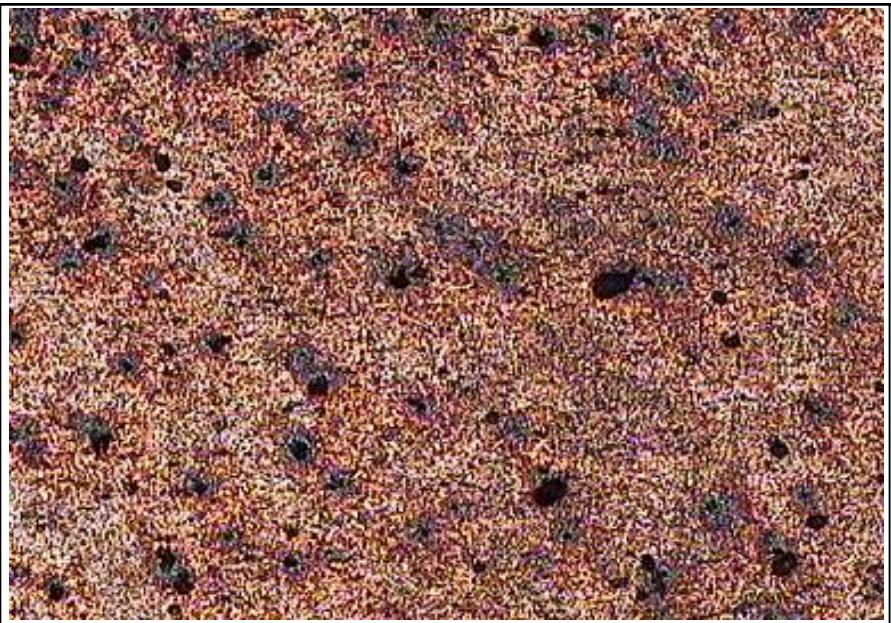


Photo.85:100x, AISI P20 Mold Tool steel, annealed. Microstructures consist of Ferrite and Carbides. Black dots are porosities.

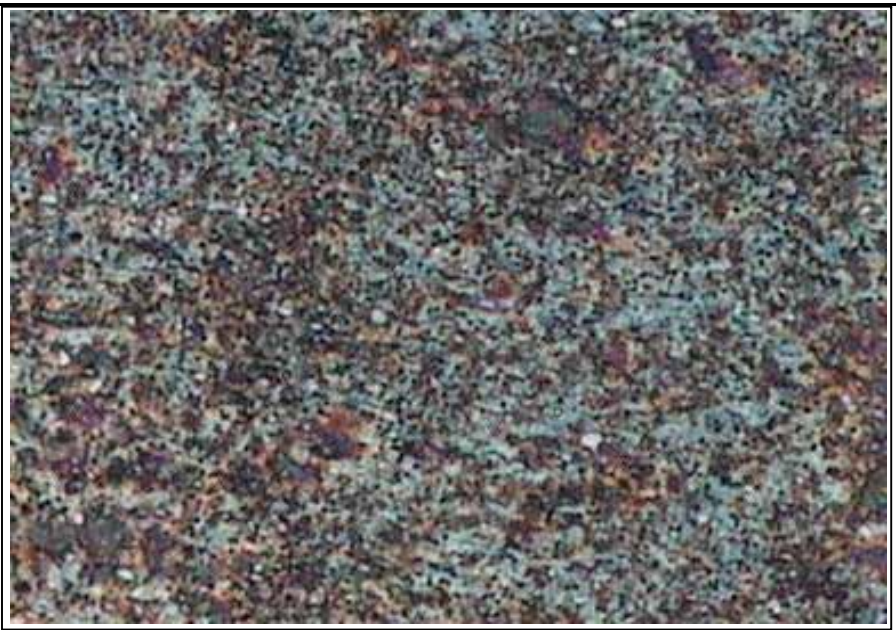


Photo.86:1000x, Same as in Photo.85, but in higher magnification.Blue-green area are Ferrite. Bright particles are Carbides.

图85：
100x，AISI P20模具工具钢，经过退火处理。该显微结构包含铁素体和各种碳化物。黑点是孔隙。

图86： 1000x，与图85相同，但放大倍数更高。蓝绿色区域是铁素体，亮色颗粒是各种碳化物。

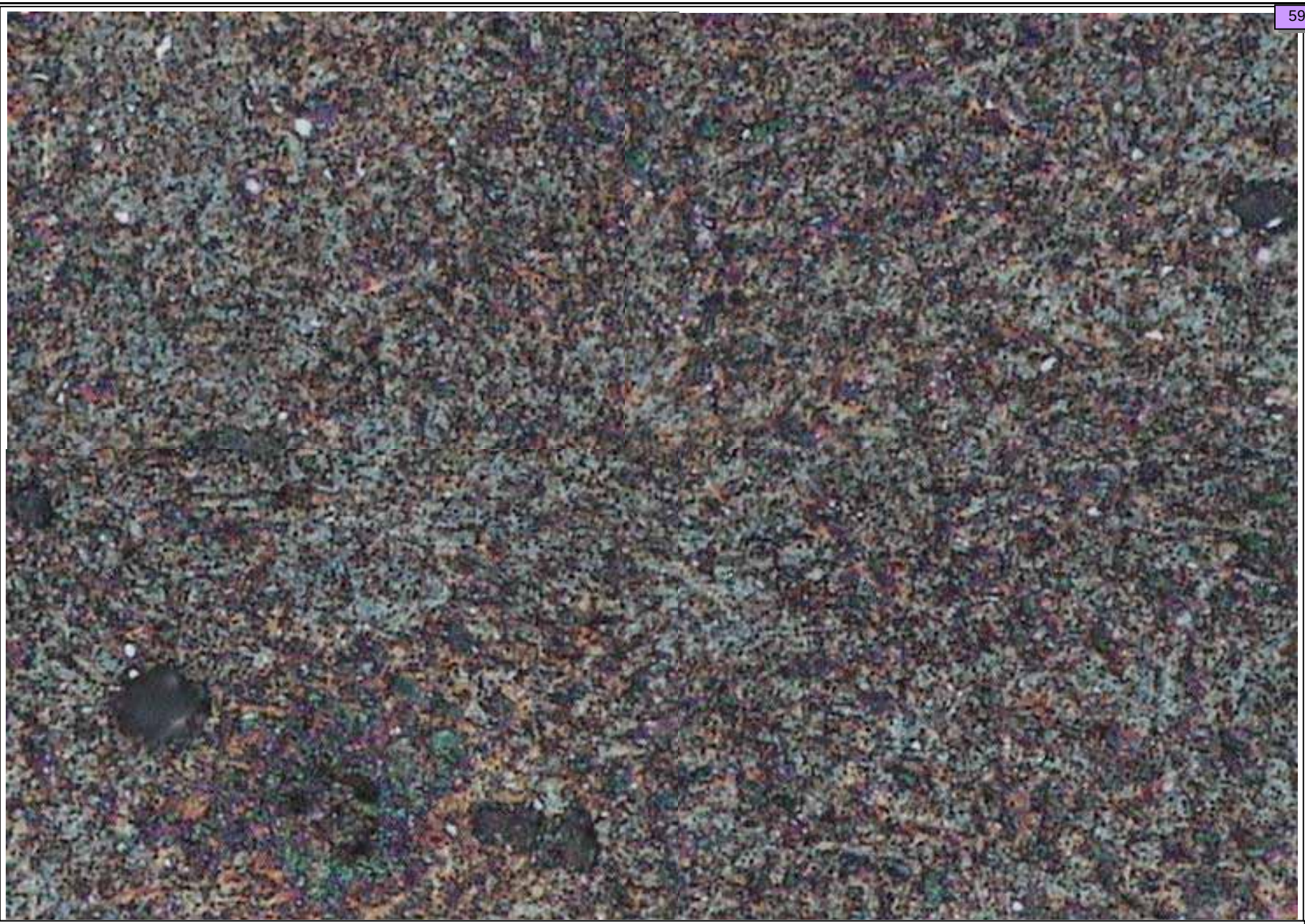


Photo.87:1000x, Same as in Photo.86, but in larger area.

图87：
1000x，与图86相同，但面积更大。

Record of Microstructures

Specimen No.: 27	Specimen name	Material	Condition 60
	Ferrous Metal	Mould tool steel (AISI P20)	Quenched and tempered

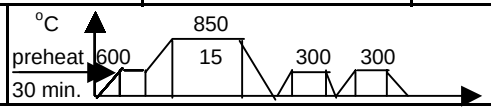
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.10 max	0.10-0.40	0.10-0.40	0.025 max	0.025 max	0.75-1.25	0.15-0.40	0.10-0.50	-	-	-	-	-

Similar steels	USA		GERMANY		FRANCE	SWEDEN		JAPAN			RUSSIA	UK
	AISI/SAE	ASTM A681	DIN	KRUPP	AFNOR NF A35-590	SS14	ASSAB	DAIDO	HITACHI	N.KOSHUHA	GOST	BS4659
	P20	P20	1.2311	2311	35CM7D	USA P20	718Supreme	PX 4	YSS: HPM 2	Plasmold20	4ChS	USA P20

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 subsequench 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 immpression has been machined. Most application is for plastic mold making.

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

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 300oC for 120 min. The microstructure will be tempered martensite. Double temper.

Microstructures

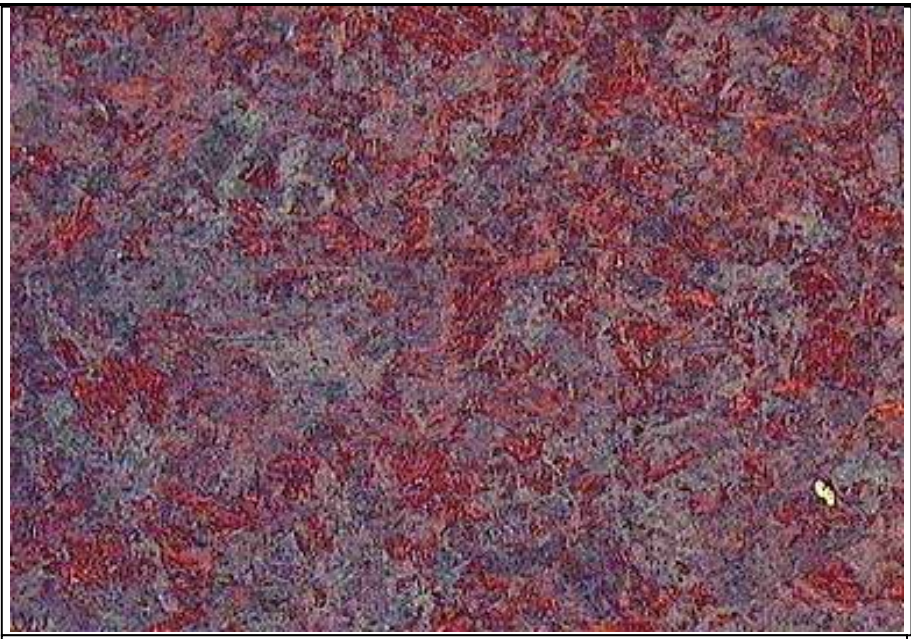


Photo.88:100x, Microstructures consist of tempered Martensite and some inclusions

图88：
100x，该显微结构包含回火处理过的马氏体及某些夹杂物。

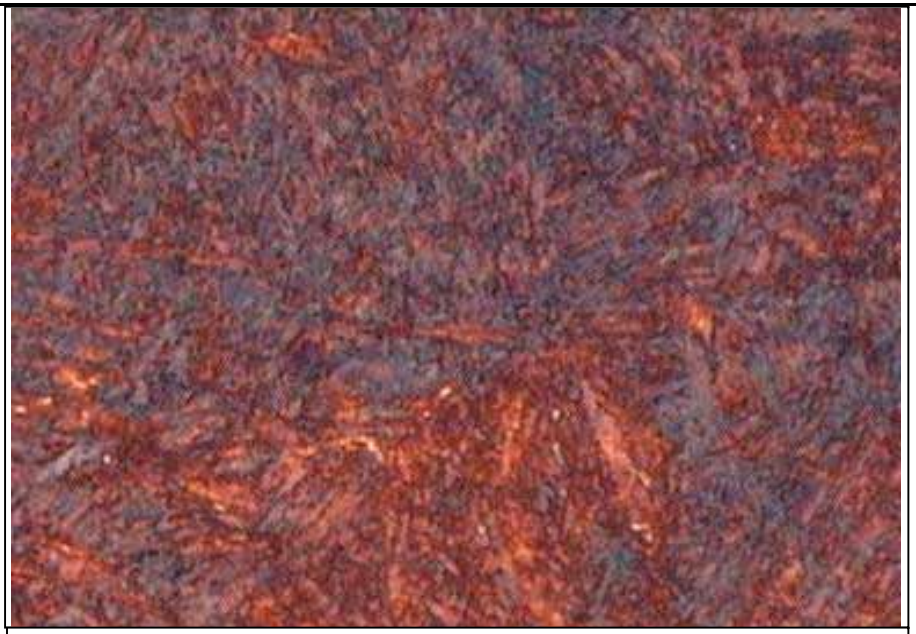


Photo.89:1000x, Same as in Photo.88, but in higher magnification. Martensite is clearly seen in brown and gray.

图89： 1000x，与图88相同，但放大倍数更高。清晰可见的棕色和灰色部分为马氏体。

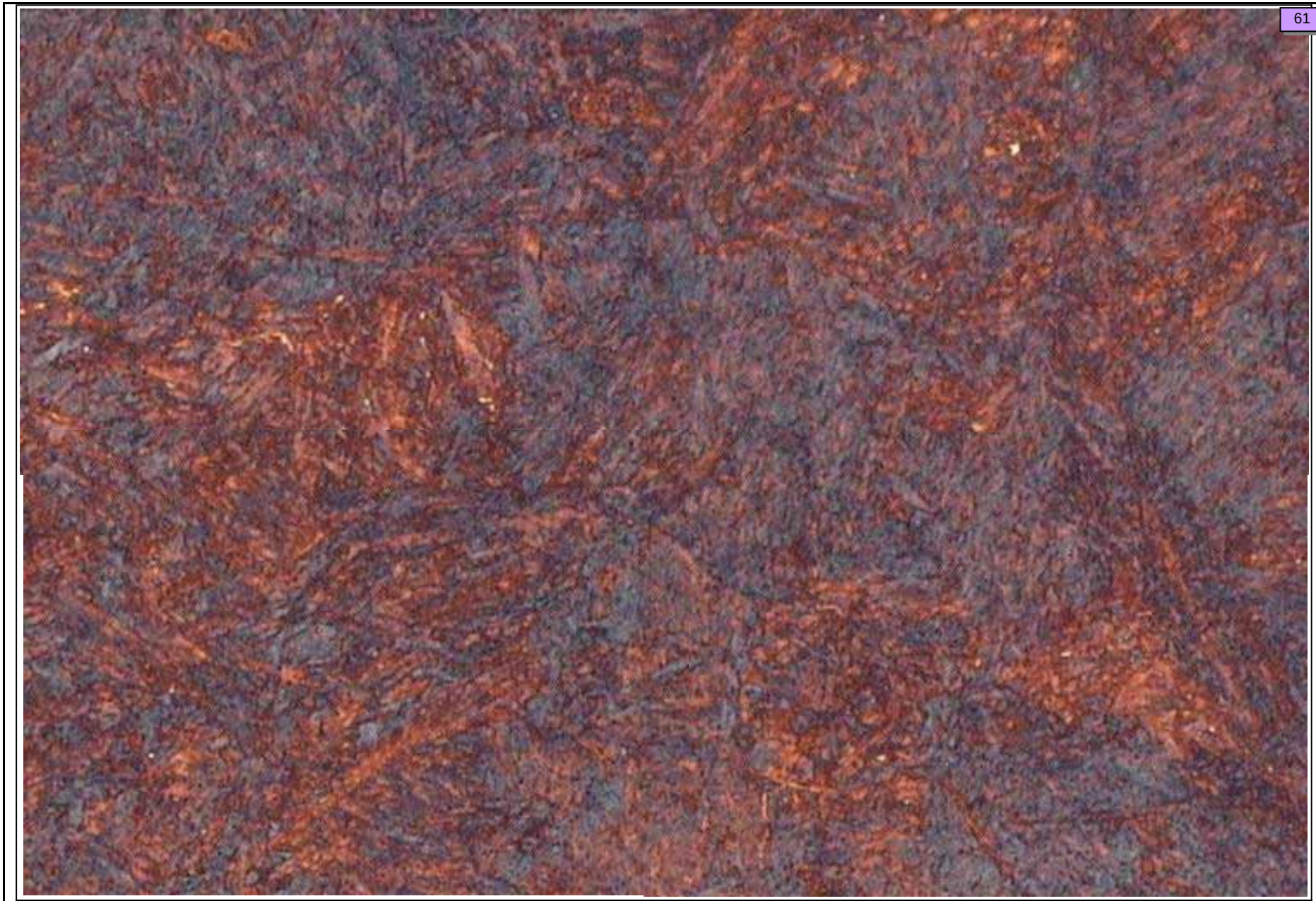


Photo.90:1000x, Same as in Photo.88, but in larger area. The strucutre is tempered martensite.

图90：
1000x，与图88相同，但面积更大。该结构是经过回火处理的马氏体。

Record of Microstructures

Specimen No.: 28	Specimen name	Material	Condition
	Ferrous Metal	High Speed Steel (AISI M2)	Quenched and tempered

62

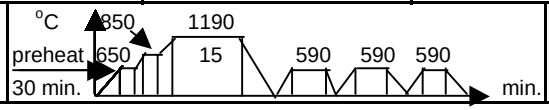
Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Co	W	Others
	0.95-1.05	0.20-0.45	0.15-0.40	0.03 max	0.003 max	3.75-4.5	4.50-6.75	0.30 max	2.25-2.75	-	-	5.00-6.75	-

Similar steels	USA		GERMANY		FRANCE	SWEDEN		JAPAN			RUSSIA	UK
	AISI/SAE	ASTM A600	DIN	Bohler	AFNOR NF A35-590	SS14	ASSAB	JIS G4403	HITACHI	N.KOSHUHA	GOST	BS4659
	M2	M2 high C	1.3345	S600	4301 6-5-2	2722	ASP-41	SKH 51	YXM 1	H 51	R6M5	BM2

Characteristics and applications: M2 is the most widely used high speed steel suitble 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	Descriptions \ Processes	Normalizing	Annealing	Stress relieving	Hardening	Tempering
	Temperature, °C	Do not normalize	870-900	650-675	Double preheat:650/850;Austenitize:1190-1230	540-595
	Soaking time, min.		60 min./inch of thickness	60 min./inch of thickness	15	120
	Quenching medium		furnace cool	air	Nitrogen quench in vacuum furnace	air
	Hardness		212-241 HB	-	64-66 HRC	65-60

Final heat treatment process of this specimen



Process: The specimen was double preheat at 650 and 850°C and austenitized at 1190°C for 15 min. in vacuum furnace. Then nitrogen quenched and triple temper at least 120 min. each for soaking time. The final microstructures will be tempered martensite and carbides.

Microstructures

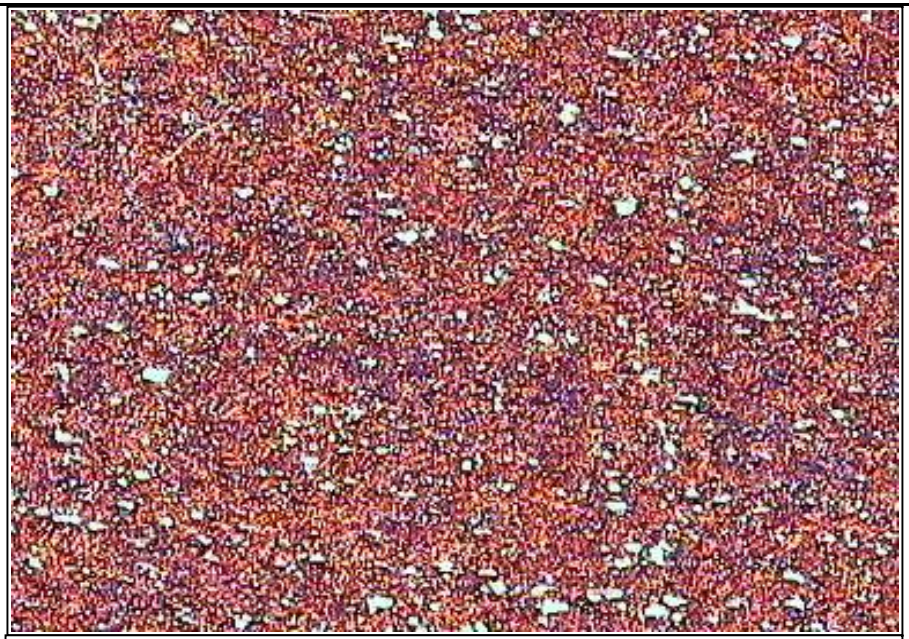


Photo.91:100x, High speed steel, quenched and tempered. Microstructures consist of Martensite and Carbides.

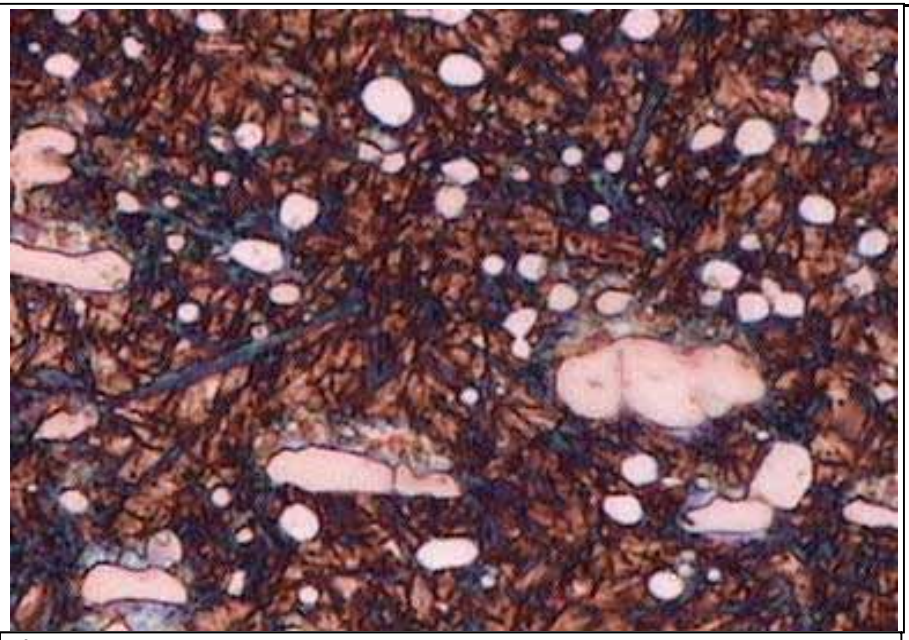


Photo.92:1000x, Same as in Photo. 91, but in higher magnification. Brown and dark gray background are Martensite. Light brown particles are Carbides.

图91： 100x，高速钢，经过淬火、回火处理。该显微结构包含马氏体和各种碳化物。

图92： 1000x，与图91相同，但放大倍数更高。棕色和暗灰色背景是马氏体，浅棕色颗粒为各种碳化物。

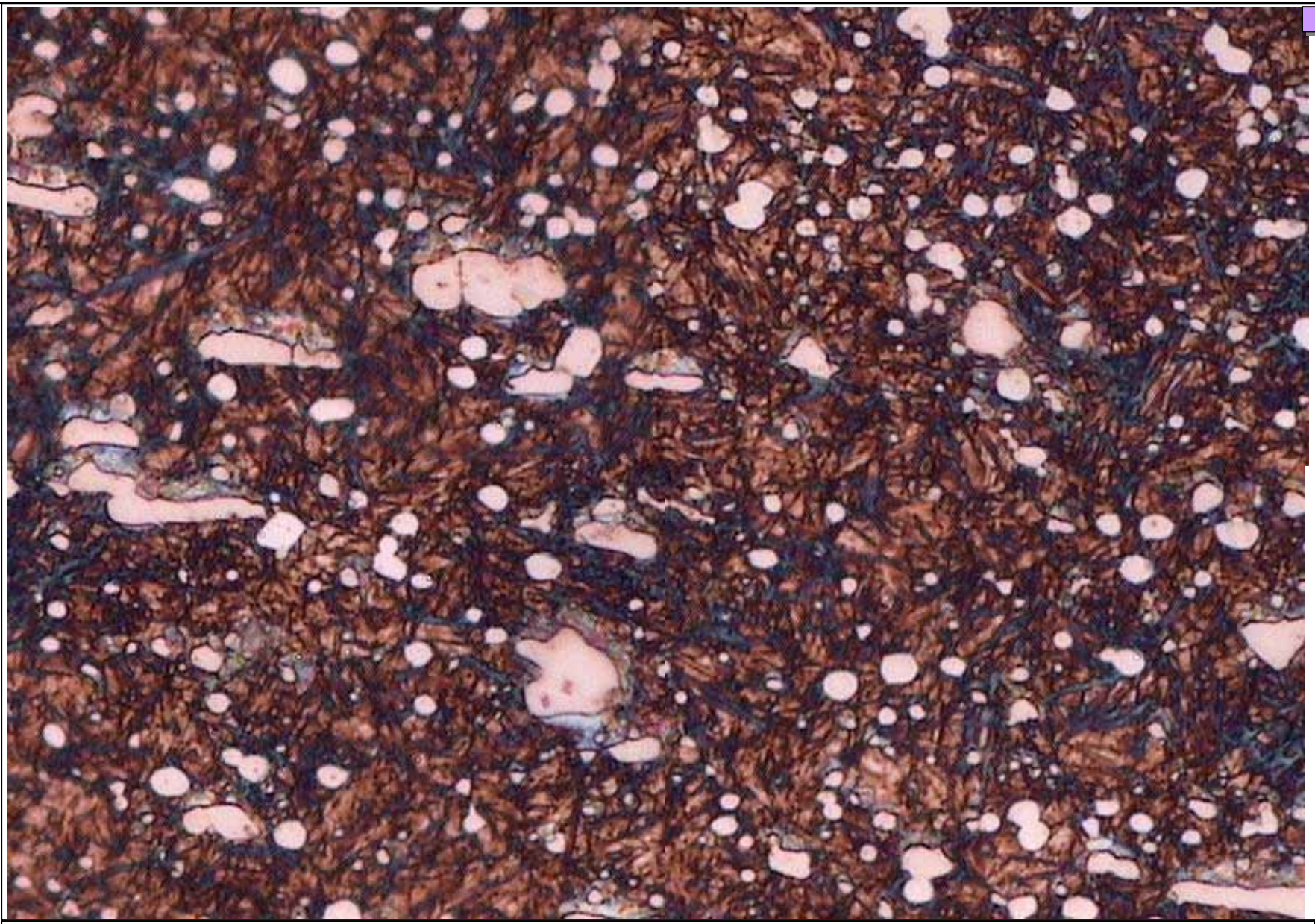


Photo.93:1000x, Same as in Photo. 92, but in larger area. Microstructures consist of Martensite(brown and dark gray needle structures), and carbides(light brown round and elongated particles).

图93：
1000x，与图92相同，但面积更大。该显微结构包含马氏体（棕色和暗灰色针状结构）及各种碳化物（浅棕色圆形拉伸颗粒）。

Record of Microstructures

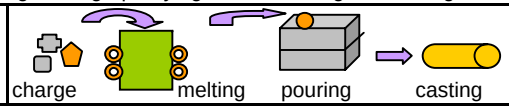
Specimen No.: 29	Specimen name	Material	Condition
	Ferrous Metal	High manganese steel	As cast

Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Cu	W	Others
	1.268	0.525	13.38	0.042	0.004	2.105	0.094	0.074	0.023	0.029	0.368	-	-

Similar steels	USA	AUSTRALIA	GERMANY	ITALY	JAPAN	MEXICO	ROMANIA	SPAIN	UK
	ASTM A128	AS 2074	DIN	UNI 3160	G5131	MNC 720E	STAS3718	UNE 36253	BS3100
	A	H19	1.3802	GX120Mn12	SCMnH3	2183	T105Mn120	AM-X-120Mn12	BW10(En 1457)

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.Example:rock crusher, bucket,wear plate, etc.

Manufacturing process of this specimen



Process: The charges (consist of pig iron, cast iron scraps, steel scraps, FeSi, FeMn, flux) were charged into 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 mould. The liquid metal will solidify as the casting then cut, mounted, ground, polished, and etched for the examination.

Microstructures

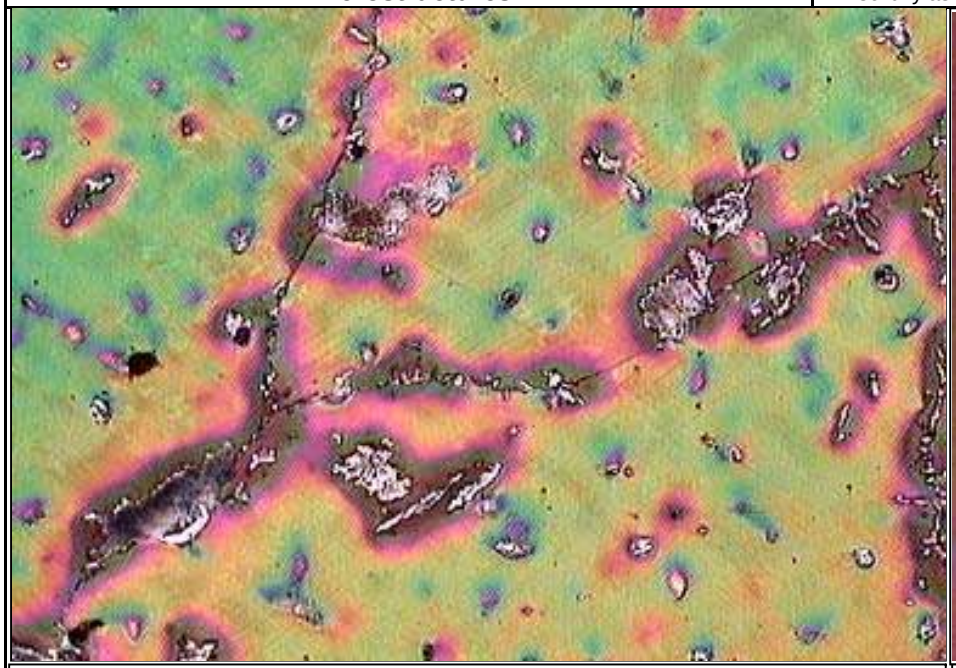


Photo.94:50x, High-Manganese steel casting, as cast. Microstructure are Austenite. White particles along grain boundaries and in the Austenite grains are Carbides.

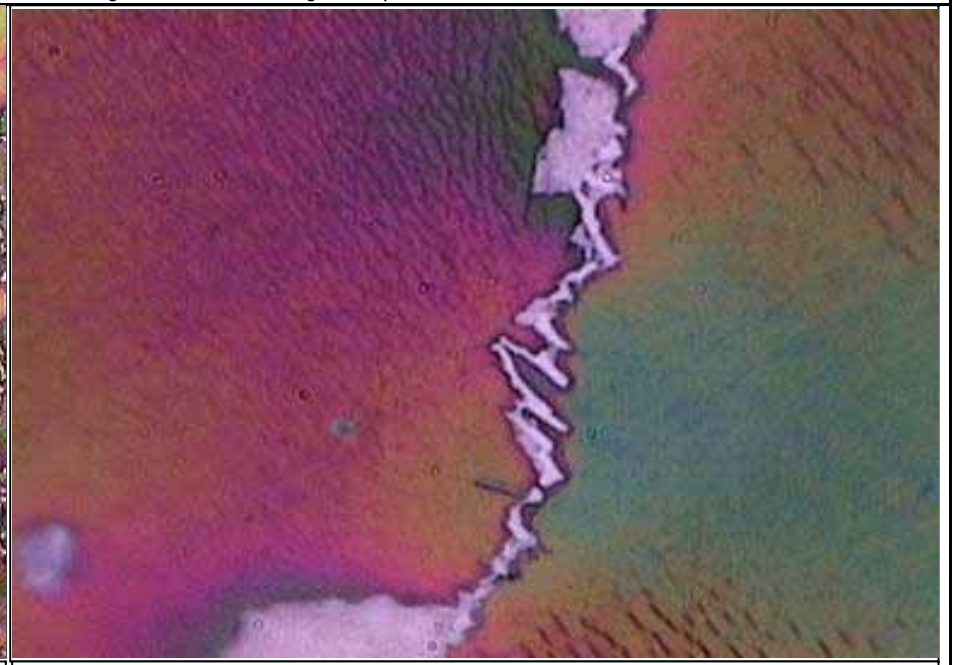


Photo. 95:1000x, Same as in Photo. 94, but in higher magnification. Austenite grains are tinted various colors. Carbides along grain boundaries are colored light purple.

图94：
50x，高锰钢铸件，经过铸造。该显微结构为奥氏体。晶粒间界旁的白色颗粒以及奥氏体晶粒内的白色颗粒均为各种碳化物。

图95：
1000x，与图94相同，但放大倍数更高。彩色部分为奥氏体晶粒。晶粒间界旁的浅紫色部分是各种碳化物。

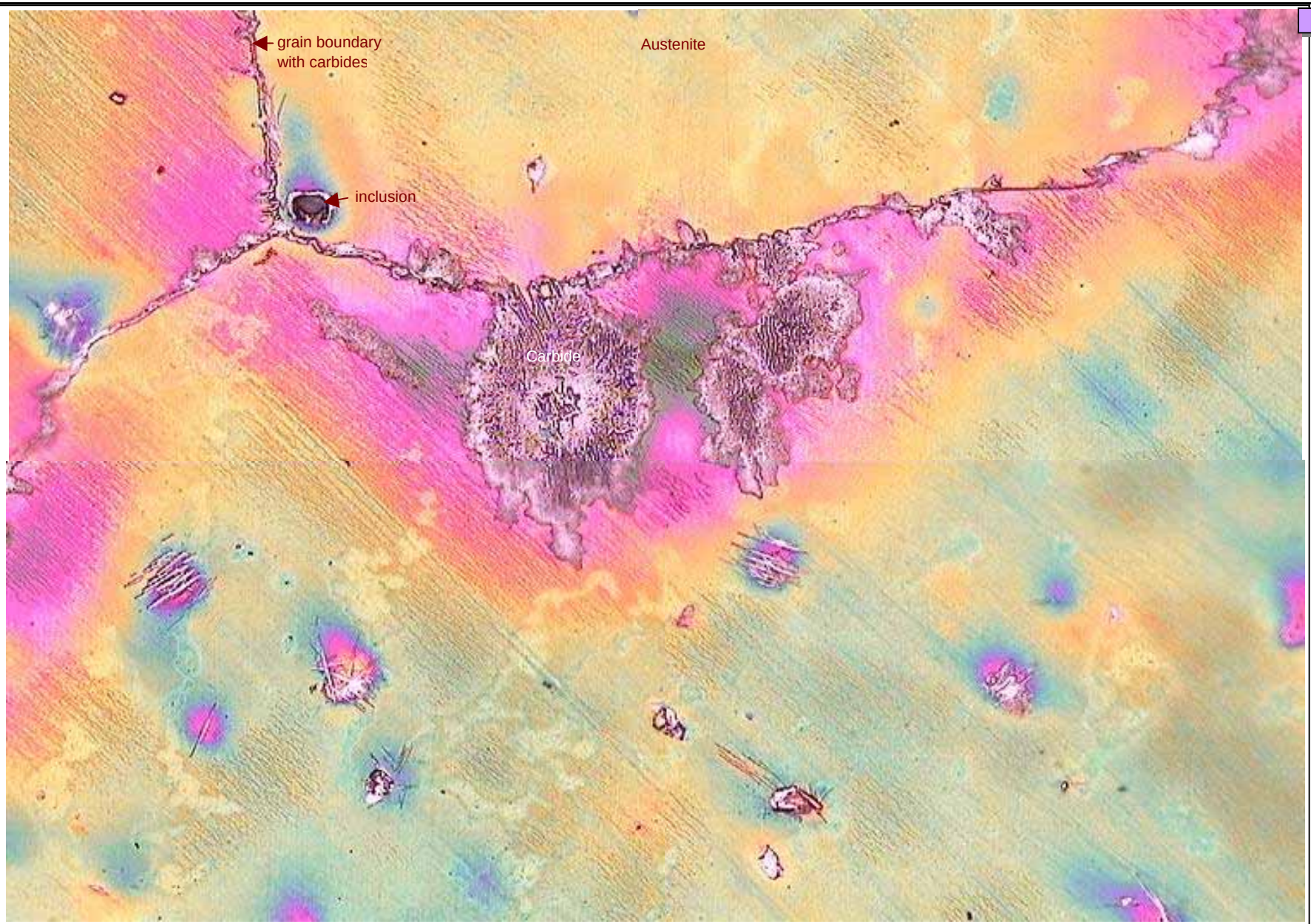


Photo. 96:200x, Same as in Photo. 95, but in larger area. Austenite grains are tinted various colors. Carbides are shown along grain boundaries and in Austenite grains.

图96：
gain boundary with carbides: 带有各种碳化物的晶粒间界; Austenite: 奥氏体; inclusion：夹杂物
200x，与图95相同，但面积更大。彩色部分为奥氏体晶粒。晶粒间界旁及奥氏体晶粒内的颗粒均为各种碳化物。

Record of Microstructures

Specimen No.: 30	Specimen name	Material	Condition
	Ferrous Metal	High manganese steel	Solution annealed

Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	V	Ti	Cu	W	Others
	1.268	0.525	13.38	0.042	0.004	2.105	0.094	0.074	0.023	0.029	0.368	-	-

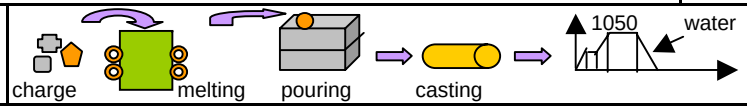
Similar steels	USA	AUSTRALIA	GERMANY	ITALY	JAPAN	MEXICO	ROMANIA	SPAIN	UK
	ASTM A128	AS 2074	DIN	UNI 3160	G5131	MNC 720E	STAS3718	UNE 36253	BS3100
	A	H19	1.3802	GX120Mn12	SCMnH3	2183	T105Mn120	AM-X-120Mn12	BW10(En 1457)

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.Example: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 variety of engineering applications. Solution annealing and quenching are the standard processes.

Solution annealing and quenching	
Temerature,°C	1010-1090
Soaking time	1 to 2 hours per 25 mm. of thickness
Quenchant	agitated water

Manufacturing process of this specimen



Processes: 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 quench in water.

Microstructures

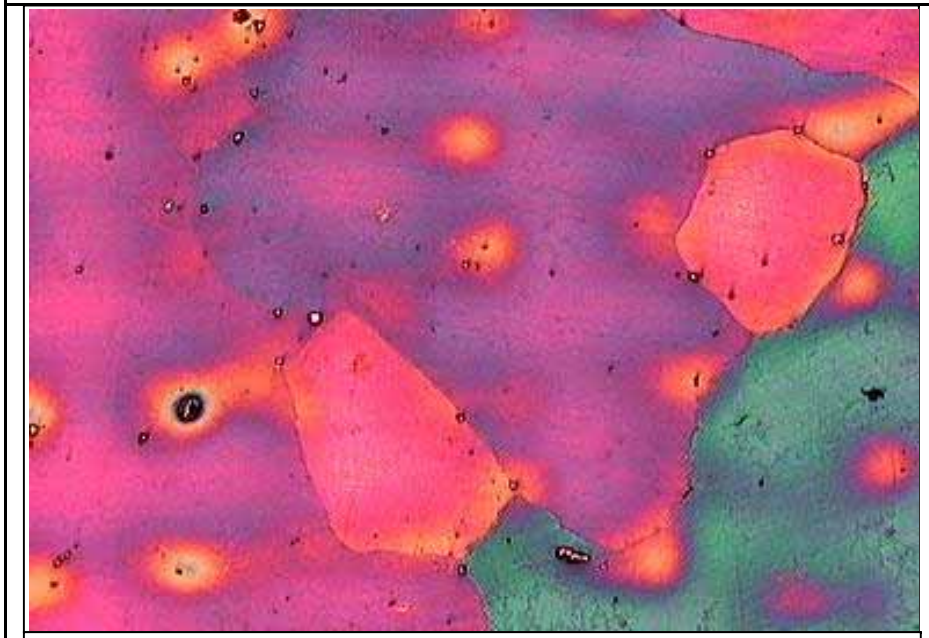


Photo.97:50x, High Manganese Steel casting, annealed. Microstructures are Austenite. The purple area shows the trace of dendrite.

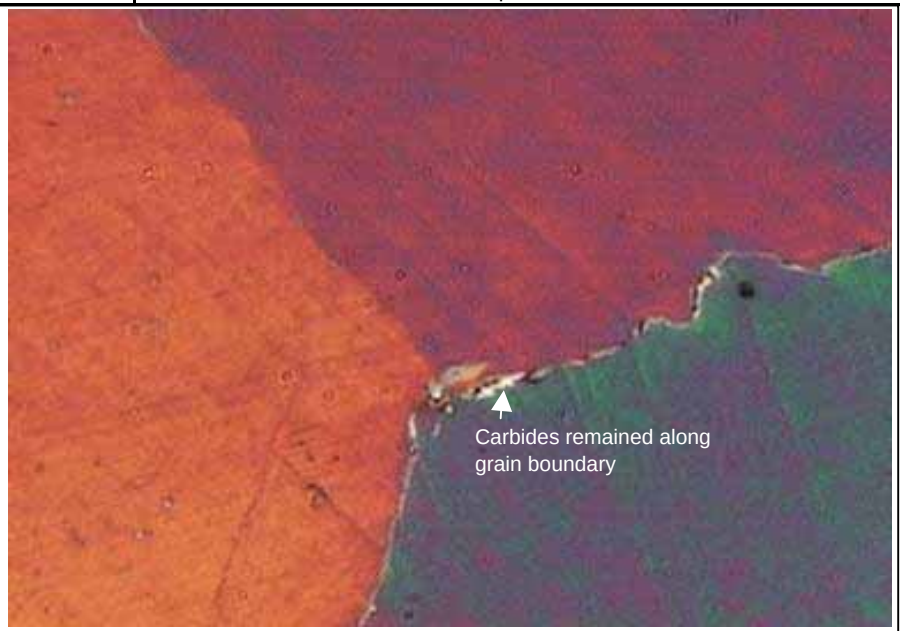


Photo.98:1000x, Same as in Photo. 97, but in higher magnification. The carbide along grain boundaries decreased after annealing.

图97：50x，高锰钢铸件，经过退火处理。该显微结构为奥氏体。所示紫色区域为枝晶的痕迹。

图98： Carbides remained along grain boundary: 残留在晶粒间界旁的各种碳化物 1000x，与图97相同，但放大倍数更高。经过退火处理，晶粒间界旁的碳化物数量减少。

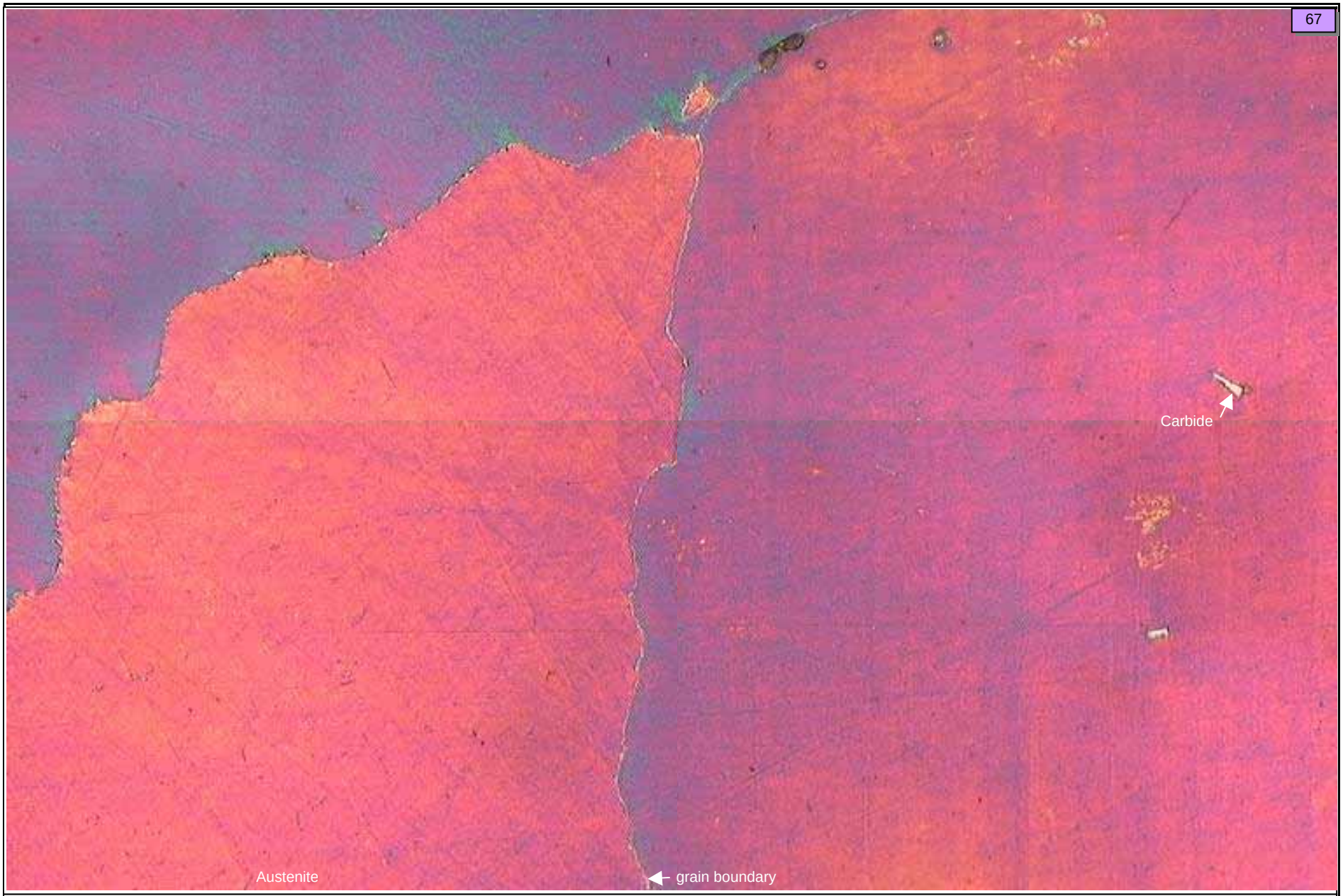


Photo.99:200x, Same as in Photo. 98, but in larger area. The microstructures are Austenite. The grain boundaries are thinner and less carbide after annealing.

图99： Carbide:碳化物; Austenite: 奥氏体；grain boundary: 晶粒间界
200x，与图98相同，但面积更大。该显微结构为奥氏体。经过退火处理，晶粒间界变窄且碳化物数量减少。