PRESI
LAB'NOTE

METALLOGRAPHIC PREPARATION OF CAST IRON

INTRODUCTION

Cast iron is an alloy of iron and carbon with a content ranging from 2.1-6.67%. These alloys offer good castability (and in liquid state, imprint easily) and have low shrinkage after solidification.

IRON
Symbole: Fe
Atomic n°: 26
Density: 7,8
Molar mass: 55,8 g.mol^{-1}
Melting point: 1538 °C

CARBON
Symbole: C
Atomic n°: 6
Density: 2,1 – 2,3 (graphite)
Molar mass: 12 g.mol^{-1}

IRON → CAST IRON ← CARBON

The production of cast iron begins with iron ore which is fed into a blast furnace along with coke (carbon). The iron is extracted from the ore by reduction. This iron is called “pig iron”. It can be used as it is for certain applications, or for making steel.

There is a second method for producing cast iron: from steel scrap and coke.
Different processes exist: cupola furnace, electric furnace or rotary furnace.

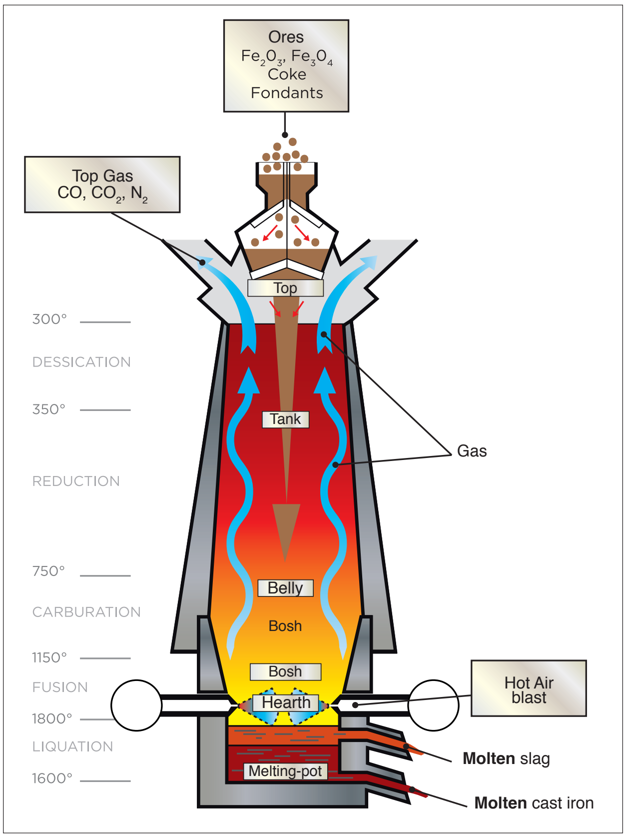

Fig. 1: Diagram of a blast furnace

It is possible to distinguish cast irons by their percentage carbon content:

• Hypoeutectic cast irons with less than 4.3 % carbon
• Eutectic cast irons with 4.3% carbon
• Hypereutectoid cast irons with more than 4.3% carbon

The Fe-C phase diagram (Figure 2) helps to explain solidification from the liquid state.

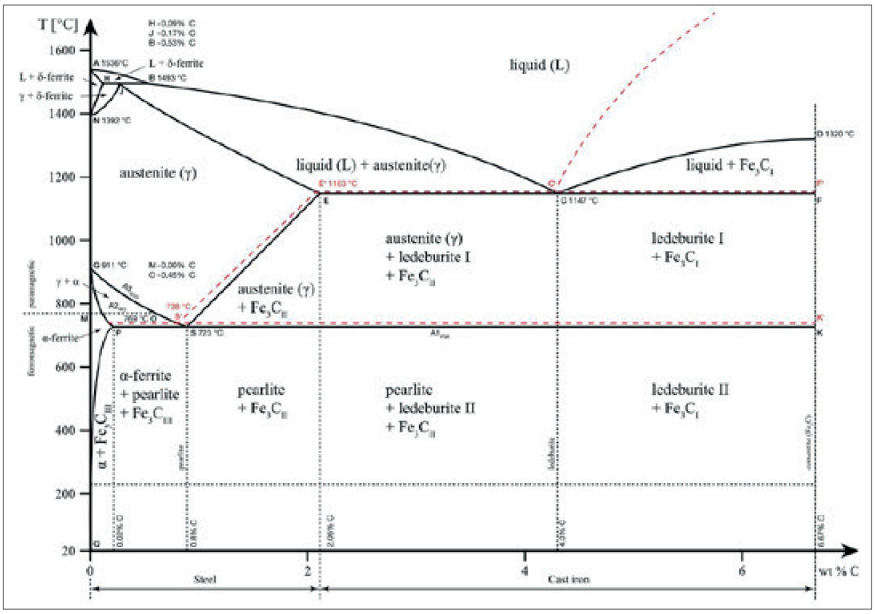

Fig. 2: Fe-C diagram

THE MAIN CAST IRONS

Generally, cast irons are classified into two main families:

WHITE CAST IRONS

The carbon is in the form of Fe3C carbide with a pearlitic matrix. Its name comes from the fact that when broken, it has a shiny white metallic appearance. White cast iron is a cast iron alloyed with manganese. The presence of chromium and molybdenum also favours the creation of white cast iron. This type of cast iron is resistant to wear and tear but is fragile to impacts.

GREY CAST IRONS

Carbon appears in the form of **(spheroidal or lamellar)** graphite. These cast irons are rich in silicon; this alloy addition favours the formation of graphite. It also improves corrosion resistance.

=> Lamellar graphite cast irons are brittle due to the geometry of the graphite which has a notch effect. Tensile strength is not optimal but it is suitable for compression work applications or if wear resistance is required.

=> Spheroidal graphite cast irons are cast irons in which the cooling has been slowed down so that the carbon crystallises in the form of a sphere. The geometry of the graphite improves machinability and the mechanical characteristics are close to those of steel. It produces a ductile, malleable cast iron. The addition of magnesium in the cast iron reduces the presence of sulphur. Thus, the graphite is formed spherically and not in lamellae.
It is possible to create spheroidal graphite cast iron from white cast iron if subjected to heat treatment.

In alloyed cast irons:
• chromium increases the mechanical characteristics
• molybdenum improves impact resistance
• phosphorus gives the cast iron better castability.

The chemical composition of the mixture is one of the parameters that will determine the type of cast iron obtained.

Cooling speed influences the formation of one or other of the cast irons.
• If the cooling is quick, it favours the formation of cementite, thus producing a white cast iron.
• However, if cooling is slower, the carbon has time to collect as graphite, producing grey cast iron.

CAST IRON DESIGNATIONS

Cast irons have a standardised designation according to NF EN 1560-1.
Their designation always starts with EN-GJ (G corresponds to a cast metal and J for iron).
Another letter corresponding to the structure of the graphite follows this beginning of the designation:

L for Lamellar
S for Spheroidal
M for annealed graphite (malleable)
V for vermicular
Y for special structure
N for no graphite

Generally, this is followed by either the required minimum tensile strength and minimum elongation in %, or the same designation as a high-alloy steel.

Two examples:
EN-GJS-400-15: Lamellar graphite cast iron, strength R min 400 MPa and elongation A 15%.
EN-GJN-X 300 Cr Ni Si 9-5-2: Graphite-free cast iron (white cast iron) with 3% carbon, 9% chromium, 5% nickel and 2% silicon

=> They are available in a wide range of cast iron grades to meet all applications according to the properties of impact resistance, wear resistance and good castability.

APPLICATIONS

Cast irons are generally used for massive objects: for example sewer manholes, stoves, car parts...

METALLOGRAPHIC PREPARATION

Obtaining an inspection surface requires a succession of operations, each one as important as the next and this regardless of the material. These operations come in this order:

• Removal of the product to be examined (if necessary), called «CUTTING».
• Standardisation of the geometry of the sample taken (if necessary), called «MOUNTING».
• Improvement of the surface condition of this sample, called «POLISHING».
• Sample characterisation: to reveal the microstructure of the sample by an etching reagent (if necessary) called «METALLOGRAPHIC ETCHING» and microscopic observation (optical or electronic).

=> Each of these steps must be carried out rigorously, otherwise the following steps will not be possible.

CUTTING

The purpose of cutting is to remove a precise section of a product, in order to obtain a suitable surface for inspection, without altering the physico-chemical properties of the cast iron.

In other words, it is essential to avoid heating or any deformation of the metal that could lead to degradation of the material. Cutting is a fundamental step which conditions the further preparation and inspection of parts.

PRESI's wide range of medium and large capacity cutting and micro-cutting machines can be adapted to any need with regard to cutting precision, sizing or quantity of products to be cut:

Fig 3: MECATOME T202

Fig 4: MECATOME T330

Each of the cutting machines in the range has its own customised consumables and accessories. The clamping system and choice of consumables are key factors in a successful metallographic cut

=> Clamping, i.e. holding the workpiece, is essential. If the workpiece is not held properly, the cut can be detrimental to the cut-off wheel, the workpiece and the machine.

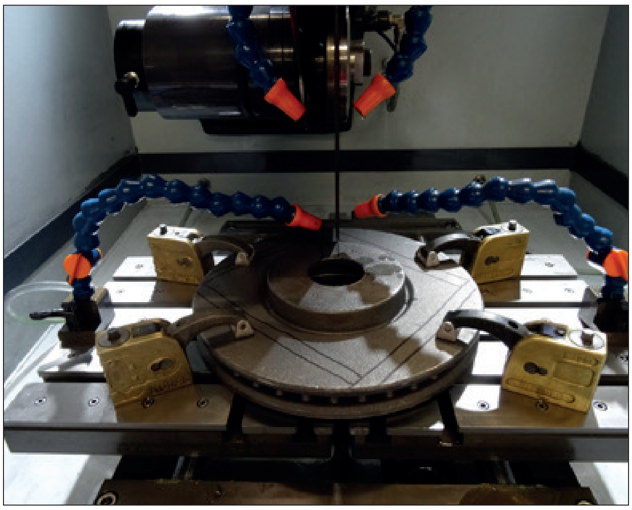

Fig. 5: Brake disc – EVO 400

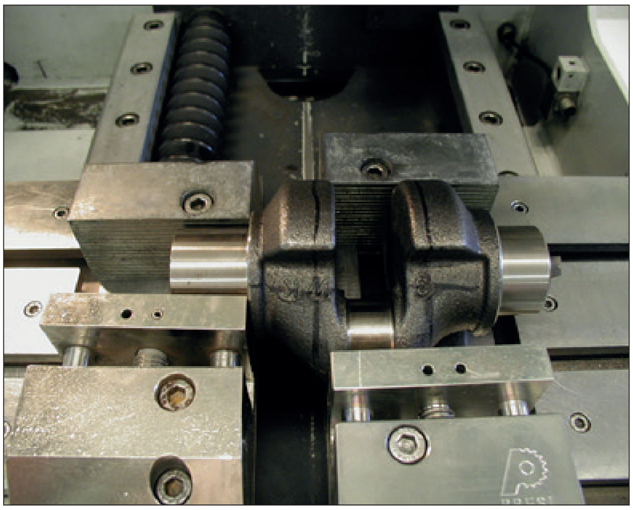

Fig. 6: Crankshaft – Mecatome T330

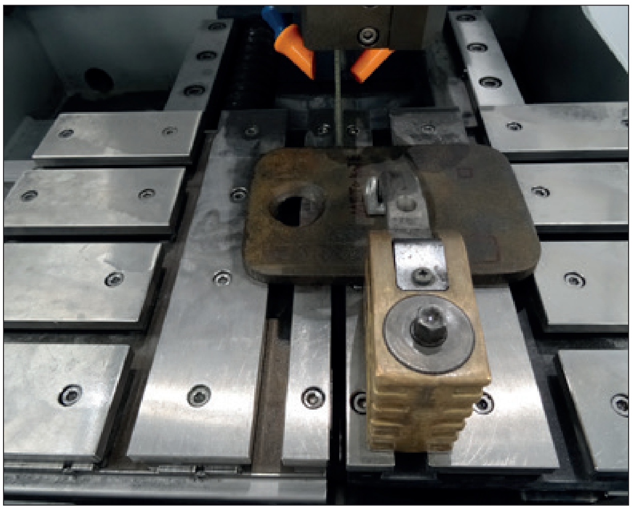

Fig. 7: Cast iron plate - Mecatome ST310

CONSUMABLES

All cutting machines are used with a lubricating/cooling liquid composed of a mixture of water and anti-rust additive in order to obtain a clean cut without overheating. The additive also protects the sample and the machine from corrosion.

	GREY IRON	WHITE CAST IRON
Micro-cutting	S (Ø 180mm) UTW	S (Ø 180mm) AO CBN
Medium-capacity cutting	F MNF AO	F AO CBN
High-capacity cutting	MNF AO	AO

Table 1: Choosing the right cut-off wheel type

=> The choice of the cut-off wheel type has to be adequate, in order to avoid cutting failure, or excessive cut-off wheel wear or even breakage. The hardness of the workpiece determines the wheel selection.

MOUNTING

Samples can be difficult to handle due to their complex shape, fragility or small size. Mounting makes them easier to handle by standardising their geometry and dimensions.

Achieving good-quality mounting is essential to protect fragile materials and also to achieve good preparation results for polishing and future analysis.

Before mounting, the specimen should be deburred with coarse abrasive paper, for example, to remove any cutting burrs. Cleaning with ethanol (in an ultrasonic tank for even greater efficiency) is also possible. This allows the resin to adhere as well as possible to the sample and thus limits shrinkage (space between the resin and the sample).

There are two mounting options:

• **HOT MOUNTING** is to be preferred for edge inspection purposes or if the metallographic preparation is carried out in preparation for hardness testing. **This option requires a hot-mounting machine.**

Fig 8: MECAPRESS 3

The machine required for hot-mounting is the Mecapress 3:

- Fully automatic hot-mounting press.
- Easy to use: memorisation, adjustment of processes and speed of execution make it a high-precision machine,
- The hot-mounting machine has 6 different mould diameters from 25.4-50mm.

+ POINT

One of the main advantages of this process is that it provides perfectly parallel faces.

• **COLD MOUNTING** is to be preferred:
• If the parts to be examined are fragile/sensitive to pressure
• If they have a complex geometry such as a honeycomb structure.
• If a large number of parts are to be mounted in series.

The cold process can be used with:

Fig 9: Pressurized mounting device

+ POINT

Substantially improves quality, in particular by reducing shrinkage, optimising transparency and facilitating resin impregnation.

Fig 10: Vacuum mounting device: POLY'VAC

+ POINT

Machine allowing vacuum impregnation of porous mounted materials using an epoxy resin.

Cold resins always leave a meniscus on the back of the coating. Before any polishing operation, this meniscus must be removed in a short step on an abrasive paper. The important thing is to make sure that this small grinding on the back of the mounting is parallel to the side where the sample is to be polished.

CONSUMABLES

To meet user needs, PRESI offers a full range of cold mounting moulds.
The cold process has different mounting moulds with diameters from 20-50mm. These are divided into several types: optimised moulds called «KM2.0», rubber, Teflon or polyethylene moulds. Cold mounting is also more flexible, hence the existence of rectangular moulds for more specific needs.

	WHITE AND GREY IRON
Hot process	Phenolic Allylic Hot Epoxy
Cold process	KM-B KM-U

Table 2: Choosing the right mounting resin type

POLISHING

The last and crucial phase in the sample preparation process is polishing. The principle is simple, each step uses a finer abrasive than the previous one. The aim is to obtain a flat surface and to eliminate scratches and residual defects that would hinder the performance of metallographic control examinations such as microscopic analysis, hardness tests, microstructure or dimensional inspections.

PRESI offers a wide range of manual and automatic polishing machines, with a wide choice of accessories, to cover all needs, from pre-polishing to super-finishing and polishing of single or series samples.

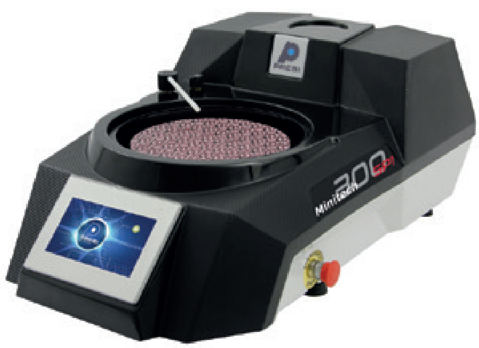

Fig 11: MINITECH 300 SP1

Fig 12: MECATECH 300 SPC

The MINITECH range of manual polishers incorporates the most advanced technologies. User-friendly, reliable and robust, they provide a simple answer to all needs.

The MECATECH range of automatic polishers allows both manual and automatic polishing. With its advanced technologies, motor power from 750-1500 W, all the PRESI experience is concentrated in this very complete range. Whatever the sample number or size, MECATECH guarantees optimal polishing.

CONSUMABLES AND POLISHING RANGES

All the polishing ranges below are given for automatic sample preparation (for manual polishing: do not take into account the parameters at the top). They are the most commonly used and are given for information and advice.

All the first steps of each range are called «levelling» and consist of removing material quickly to level the surface of the sample (and resin). Those given below are standard and can therefore be modified as required.

Applied pressures vary according to sample size, but in general the following applies: 1daN per 10mm mounting diameter for the pre-polishing steps (ex: Ø40mm = 4 daN) then reduce force by 0.5daN at each polishing step with an abrasive suspension.

The following is a general polishing range for **cast iron:**

N°	Support	Suspension / Lubricant	Platen Speed (RPM)	Head Speed (RPM)	Rotation direction platen / head	Time
1	P320	Ø / Water	300	150	→ →	1'
2	TOP	9µm ADS poly / Lub ADS	150	135	→ →	4'
3	STA	3µm ADS poly / Lub ADS	150	135	→ →	3'
4	TFR	1µm ADS poly / Lub ADS	150	135	→ →	1'

NB: Levelling with P320 abrasive paper is sufficient for a sample from a metallographic cut. If more material removal is required, a larger grit-size should be used.

For pre-polishing, the head and plate rotation direction should not be reversed, as this can detrimentally affect flatness. However, reversing rotation direction can help if a large amount of material has to be removed.

Cast iron polishing can be performed using a mono-crystalline diamond suspension (alcohol-based, water-free). This prevents oxidation of the cast iron, which is sensitive to water during the finishing polishing steps.

When cleaning between steps, rapid drying with compressed air after cleaning with water is recommended, or cleaning with ethanol to limit the emergence of corrosion points.

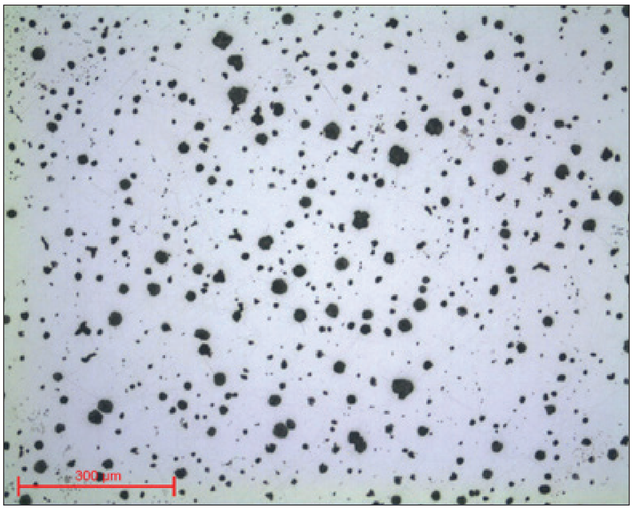

Fig. 13: Cast iron GS lens x10

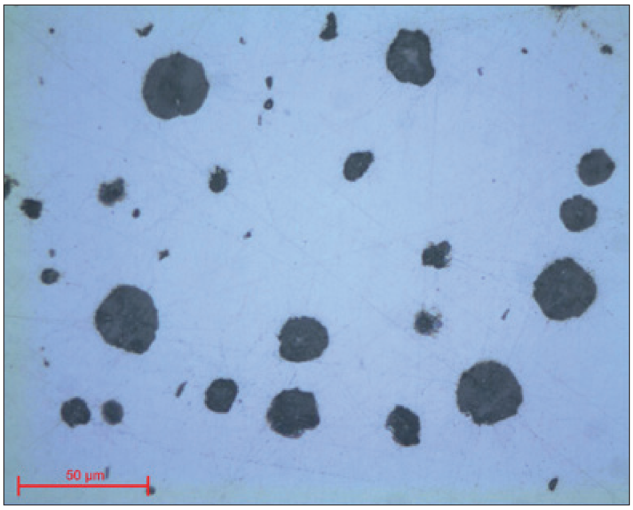

Fig. 14: Cast iron GS lens x50

A second polishing range can be used for **cast iron** polishing:

N°	Support	Suspension / Lubricant	Platen Speed (RPM)	Head Speed (RPM)	Rotation direction platen / head	Time
1	I-Max R 54µm	Ø / Water	300	150	→ →	3’
2	MED-R	9µm super abrasive MED-R	150	135	→ →	4’
3	STA	3µm ADS poly / Lub ADS	150	135	→ →	3’
4	TFR	1µm ADS poly / Lub ADS	150	135	→ →	1’

In this second range, levelling is performed using a 54µm I-Max R instead of abrasive paper. This resin-bonded diamond disc, suitable for polishing hard materials, maintains good flatness and can replace several hundred abrasive papers.

The second stage is performed using a MED-R disc. This support comprising resin pads, to which a super abrasive suspension for MED-R is added, maintains good flatness and offers a longer service life than a polishing cloth.

The finishing stages are performed using ADS suspension. A concentrated LDP polycrystalline suspension can sometimes be suitable, if the cast iron does not corrode or does so only slightly.

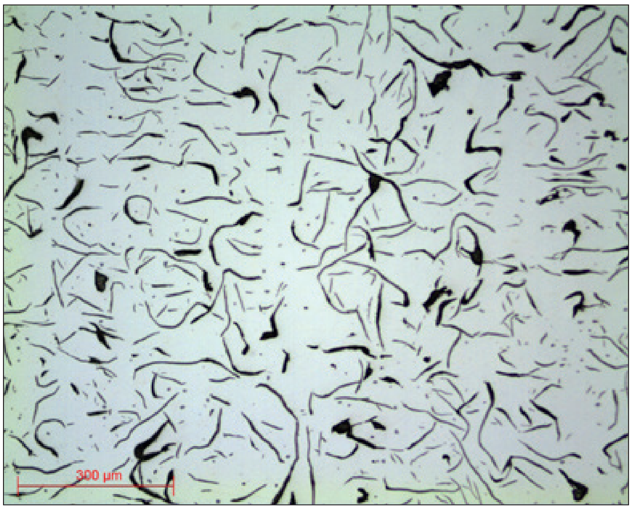

Fig. 15: Cast iron GL lens x10

Fig. 16: Cast iron GL lens x50

MICROSTRUCTURE

The structure of the cast irons can be revealed using different etching reagents:

- Nital reagent 4%
- Picral's reagent
- Chatelier's reagent

The list is non-exhaustive; as cast irons structures are close to that of steel, some reagents are common to both materials. All the micrographs presented were created using the **PRESI VIEW** software:

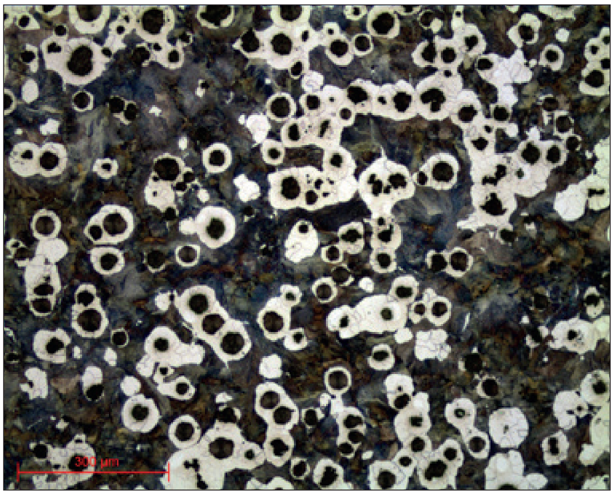

Fig. 17: Cast iron GS lens x10

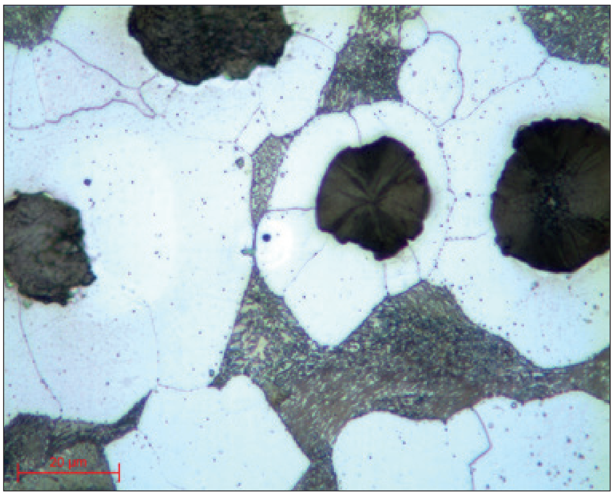

Fig. 18: Cast iron GS lens x100

Fig. 19: Cast iron GL core lens x10

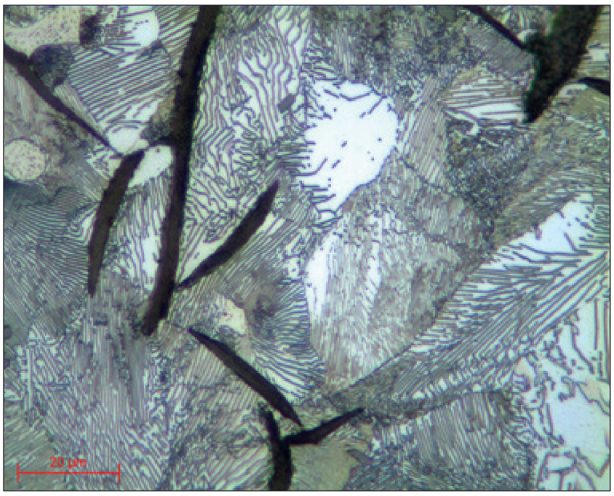

Fig. 20: Cast iron GL core lens x100

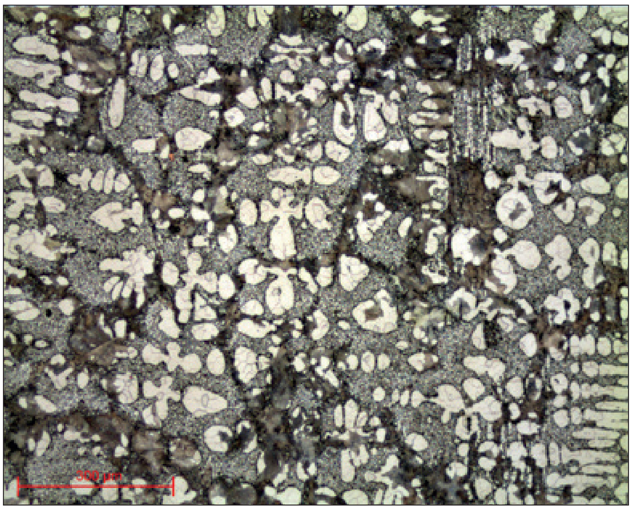

Fig. 21: Cast iron GL edge lens x10

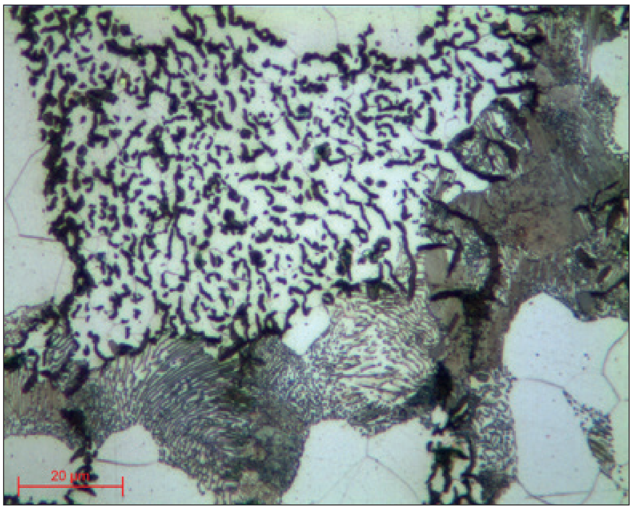

Fig. 22: Cast iron GL edge lens x100

=> All the structures appearing in figures 17-22 were revealed using 4% Nital reagent.