Journal of Engineering in Industrial Research

2023, Volume 4, Issue 2

# Original Article: Investigating the Microscopic Structure of Cast Iron and Its Application in Industry

**Milad Karimi***

*Faculty of Engineering, Department of Mechanical Engineering, Yadegar -e- Imam Khomeini (rah), shahr-e-rey Branch, Iran*

Use yor device to scan and read the article online

Citation M. Karimi*. **Investigating the Microscopic Structure of Cast Iron and Its Application in Industry.** *J. Eng. Ind. Res.* **2023**, 4 (2):77-85.

https://doi.org/10.48309/JEIRES.2023.2.2

**Article info:**
**Received:** 2023-05-04
**Accepted:** 2023-07-28
**ID:** JEIRES-2307-1084
**Checked for Plagiarism:** Yes
**Editor who Approved Publication:**
Professor Dr. Mohammad Haghighi

**Keywords**:
Cast Iron; Silica; Microscopic Materials; Metallography.

## ABSTRACT

**Introduction:** Metallography in the general sense is the study of the internal structure of metals and alloys and the relationship of this structure with the composition, production sample, and freezing conditions and their chemical and mechanical properties. One of the important tests of the quantitative and qualitative control unit of the metallographic casting production line, which today has both the quality control and research aspects. Gray cast iron will be produced from an alloy of iron and carbon that is about 2% more or a low cooling rate or silicon that causes instability of cementite. Now, if its carbon content is less than 4.3%, low carbon gray cast iron is obtained, which is easier to cast than steels, which may have merit and pearlite properties.
**Method:** In the initial stages of cutting the sample from the main piece, we find out its clarity, softness and well-cut.
**Findings:** After cutting, it can be filed easily, but sanding it was difficult due to its high softness, so that by spending about 1.3 of the time on sanding cast irons like before, we would reach a flat surface. We put all the files and polishes of the sample under the microscope.
**Conclusion:** At first glance, the overly sanded lines and the polishing machine prevented one from seeing its graffiti. In equipment that wears, iron alloys with the most carbon have the best wear resistance, but due to the many stresses that occur during work, the material used should have sufficient toughness to prevent various defects.

## Introduction

Metallography in the general sense is the study of the internal structure of metals and alloys and the relationship of this structure with the composition, production sample, and freezing conditions and their chemical and mechanical properties. One of the important tests of the quantitative and qualitative control unit of the metallographic casting production line, which today has both the quality control and research aspects [1-3]. If we want to know more about the importance of this laboratory, it is necessary to state and pay attention to the important goals of this laboratory.

1. Investigating the microscopic defects and some of the macroscopic defects of the produced metals and alloys, such as coarseness, growth, heterogeneity of

***Corresponding Author: Milad Karimi** (daktil1367@gmail.com)*

unwanted phases, and non-uniform distribution of grains and phases.

2. The approximate diagnosis of chemical composition of the alloy by examining the internal structure and using the phase diagram of that alloy, which is more necessary when the facilities of the metal analysis laboratory are not available [4].

3. The macroscopic method is mostly used and it is an aid for the freezing laboratory, and it consists of: controlling the way, type of freezing, and macroscopic growth of grains and the relationship with the casting conditions of that alloy, which control can be effective in improving the mechanical properties and health of the cast piece. It should be mentioned that the initial goal is much more important among the mentioned goals and we divide it into two main parts [5].

- ✓ Technological aspect.
- ✓ Metallurgical aspect.

### *Gray cast iron*

A large part of cast iron is gray cast iron, which is usually called cast iron. Of course, the mentioned title is inappropriately used to define gray cast iron, while the name gray cast iron was chosen because the color of the fracture section is gray. The gray color of the broken cross section of this alloy is due to the presence of thin graphite sheets in gray cast iron. When the chemical composition of molten cast iron and its cooling speed are suitable, during solidification, the mentioned carbon in cast iron is separated and sheets of graphite are formed. The grains of these graphites grow into the melt, and thus they act freely to form sheets. The presence of sheet graphite causes gray cast iron to have unique characteristics, including good machinability in conditions where the degree of hardness is at a level where the wear resistance is excellent. The ability to resist burning in the last stages of the loss of lubricants is good, as well as the unusual elastic property making it able to vibrate. Several different factors affect the germination and growth of graphite sheets, so that these graphite sheets can appear in different shapes and forms [6].

The amount of graphite in cast iron, its size, and distribution method are also effective on the properties of cast iron, it is important to determine the desired properties. A type of background structure in cast irons with sheet graphite has less effect on the strength of these cast irons than the shape, size, and distribution of graphites. If the type of background structure is an important factor in determining the hardness and machinability of these cast irons. Another group of cast irons, which are very important in engineering materials, are cast irons with spheroidal graphite or brittle cast irons (Figure 1) [7].

The graphites shape in the casting conditions of these types of cast irons is spherical and they have appropriate strength and relative length increase. The structure of the background in this type of cast iron has a great effect on their strength. Less amount of silicon in cast irons or more alloying elements such as wormwood and a set of factors preventing the decomposition of carbon causes that the third category of cast irons is called white or high hardness cast irons, low machinability and resistance to white failure. Meanwhile, the shape of graphites changes compared to the type of malleable cast iron, which means that their range of changes starts from coated and compacted graphites and ends with completely spherical graphites, and this is the composition of the background phase in this the type of cast iron starts from a ferritic structure and ends with a pearlite structure. In the microscopic structure of cast iron, phases and compounds such as ferrite, pearlite, or other changed phases that form the background of the sample. They surround the graphites or work of eutectic beads. Such eutectic alloy components are frozen in granular or cellular form during freezing [8].

**Figure 1:** Pure iron (soft iron - wrought iron).

### *Gray cast iron*

The aim of the experiment is to investigate the microstructure of gray cast iron before and after etching [9].

**Test theory:** The piece of gray cast iron is initially made into a bag with a file, and then its surface is polished with sandpapers, and after finishing the sanding process, it is polished and placed in an etching solution. After sanding, we take and wash it with water and put it under the microscope. Of course, before etching, no other details could be seen under the microscope except the graphite sheets, but after the etching stage is finished, it can be seen. It contains sheet graphites with a completely pearlitic background and eutectic phosphide, and the dendritic structure related to the primary astents is very weakly seen in it.

**Structure of primary dendrites in gray cast irons:** By performing H polishing operations and microscopic or normal microscope tests, the shape of primary dendrites in pre-eutectic gray cast irons cannot be observed. If a sample of recent cast iron is sanded and polished with great precision and delicacy, using a light source and reducing extra lights and placing the sample appropriately, the mentioned structure can be clearly seen. The samples are prepared and prepared using soft sandpapers placed on the rotating discs, and then they are studied by inclined light and by adjusting the sample direction and of the light to create the maximum light contrast. First, delicate islands of dendrites with a radial and secondary structure, coarser, and directionless dendrites in the sample observed at a slower speed (Figure 2) [10].

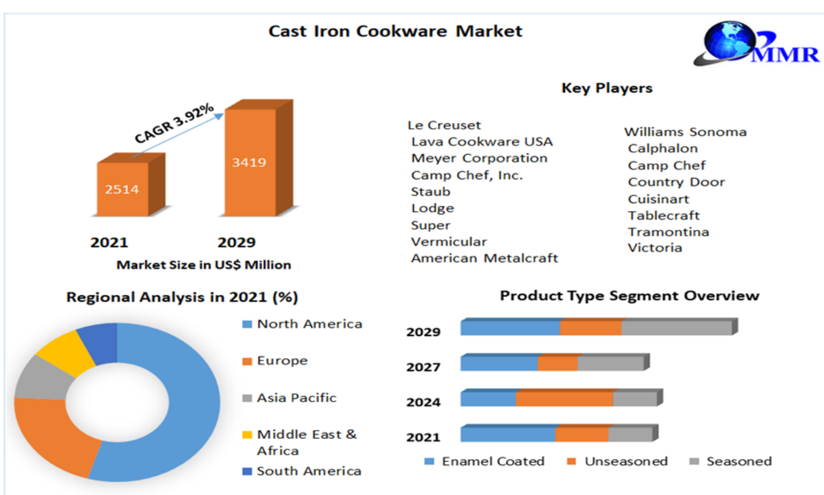


**Figure 2:** Gray cast iron.

### *Change of equivalent carbon in gray cast iron*

The amount of sheet graphite is the most important factor that affects the strength and other properties of gray cast iron, and the change in them is the main reason for the change in the strength of cast iron. The structure of the background is complete pearlite if the amount of silica is less or the amount of manganese is more, and in the same way, due to the presence of very small and partial amounts of pearlite stabilizing elements such as arsenic, cerium, copper, nickel, and tin in the raw materials or returned scraps. A completely pearlite background can be obtained. In the case of cast irons with less strength, the background structure is less important than the type of graphites in cast iron. In the case that in cast irons with high strength and resistance, the type of background structure is very important, so in such cases, they try to produce completely political or visual structures.

### *Investigating the structure of white cast iron*

White cast iron is an alloy of iron and carbon with an amount of more than 1.7% carbon in a semi-stable system, which turns into white cast iron either due to the presence of the alloy elements of carmine, vanadium, sulfur, molybdenum, or due to high cooling speed, and the name *white cast* iron is taken from its cross section which is white and crystalline. The color of the white surface is broken due to the absence of graphite from the background. The difference between cast iron and gray cast iron is that in white cast iron there is rarely free graphite and there is carbon in the form of $Fe_3C$ cementite phase, which is extremely hard and brittle due to the presence of this phase. Hypervertices is divided.

### *Malleable cast iron*

Basically, malleable cast irons are low-alloyed or non-alloyed pre-eutectic cast irons, which are subjected to thermal and framing operations to create compact spherical graphites, and also access to a set of strength and softness. Malleable cast iron parts are first casted as white cast iron, which means that all the carbon in this cast iron is in a composite form in the condition of black cast iron, and then in the stage of thermal operation by heating up to the austenitic zone and keeping the part at this temperature for a sufficient time. Iron carbide is decomposed in it and malleable iron is obtained. Heating the parts up to the austenitic region causes the accumulation of carbon in different areas, and after a certain period of time, carbonaceous carbon is formed in an austenitic background, and finally, the continuation of radiation and the use of a suitable heating process and also the cooling speed can make the structure of the cast iron background from ferrite. It completely changed a political structure [11].

### *Malleable cast iron with pearlite background*

Malleable pearlite cast iron contains spongy carbons in the fields of pearlite and strip or spherical pearlite, which has more strength and flexibility than ferritic malleable cast irons.

Different types of malleable cast iron with pearlite background can be produced by one of the following methods:

1. Austenitizing, quenching, and tempering of a ferritic malleable cast iron.
2. Conch in the air, playing after the completion of the initial stage framing.
3. Conch in a liquid, annealing after finishing the radiation of the initial stage.
4. Annealing in air, reheating, and quenching in a liquid after finishing the framing of the first stage.

### *Purpose of polishing and etching*

A question may arise that what is polishing and etching? Polishing is fine sanding which is made up of waterproof sandpapers that are made up of numbers 1000-320 and installed on the aluminum metal which is placed under a tap and water is constantly poured on it during sanding. Etching means making the crystalline structure of the metal visible and creating a contrast between its different manufacturers.

### *Description of the experiment or how to do the work*

The first thing that needs to be done is to cut a piece with the required dimensions from a simple grooved rebar, which in this case is 1 cm. After cutting the piece of that file, we sand the fence and the surface of this sample and hit the entire surface with rough and soft files until it reaches the right size and the surface is sanded. After finishing filing, we come to the sanding or polishing part. In this part, we put the sample on the place where the sandpapers are placed from soft to rough on the platform to start sanding in order. At the same time, water taps are installed on each of the sandpapers so that water can be poured on the sandpaper sample while working and we can do the work better and more smoothly. The reason why the water should be continuous on the sample is to prevent the sandpaper from blocking or to prevent the line on the sample.

The working method is that we first use rough sandpapers and move to the soft side in order of number to remove the scratches on the sample, and also use sandpapers until this is done. After finishing the work and making sure that there are no scratches, it is time for the polishing machine. Devices with a plate that rotates by electromotive force and a fabric is installed on this plate, the name of this fabric is mahout, and the way it works is that when the plate rotates, the sample is placed on it so that if there is a scratch on the piece, it can be removed and the reason for that is the friction between the fibers of the mahout fabric and the surface of the piece, which causes scratches to be removed.

To do this faster, the web hatter mixes aluminum oxide with water, which turns white, and when the plate rotates and the sample is placed on it, this solution is poured on it, and the aluminum oxide grains collide with the sample surface, causing it to disappear. There are scratches on the piece. After washing and drying the surface of the sample, we prepare it for etching. The etching solution is variable for each piece and for the steel bowl piece; it is nitric acid and alcohol. To do the work, we have to place the sample inside the etching solution. Of course, the time to put it inside the solution depends on factors such as the type of metal, the structure, and water hardness, and it can vary from 1 to 5 seconds. We clean its surface with alcohol and then dry it. Now, the sample or pieces are ready to be observed through a microscope so that we can study the structure of this steel [12].

### *Unbreakable cast iron*

Ductile iron is also known as spheroidal iron, spheroidal graphite iron, and SG iron. Due to the amount of carbon and silicon content, ductile iron belongs to the family of gray iron, and in terms of melting equipment, melting maintenance temperature and general metallurgy, these two are very similar. The main difference between ductile iron and gray cast iron is that the graphite of ductile iron is released in the form of spheres during solidification, while the graphite of gray cast iron is released in the form of sheets. The release of spherical graphite in ductile iron is caused by the presence of a few hundred percent of magnesium metal in the melt. Since the presence of a small number of elements such as sulfur, lead, titanium, and aluminum can affect or even prevent the spheroidization of graphite, it is necessary to use molten cast iron to prepare ductile iron compared to the melt used for gray cast iron. goes. In terms of the absence of impurities, it should be in a better condition.

Adding a small amount of sodium along with magnesium to the melt minimizes the effect of impurities that prevent the formation of spherical graphite, and therefore the necessary conditions are provided to produce cast iron from relatively cheap raw materials. If there is sulfur in the primary cast iron, magnesium sulfur is formed and causes some of the magnesium to dissolve and become unusable, and magnesium sulfur also creates slag. Therefore, the low amount of sulfur in the primary ingot or the raw iron used is of particular importance. Of course, since good flexibility is one of the important properties of ductile iron, the number of stable elements of controlling carbide and pearlite, for example, elements such as chromium, vanadium, manganese, tin, and phosphorus should be further low. The amount of phosphorus in cast iron should not be more than 0.06%. Especially if it is necessary, the production ductile iron has good impact resistance at low temperature [13].

### *White cast iron*

All eutectic carbon in non-alloyed cast iron parts that have thin and medium thickness during solidification in sand molds and contain less silicon. Without the use of inoculation, germinating materials turn into iron carbide. Such cast irons have white fracture sections and are called white cast irons. These types of cast irons are used in a non-alloyed form and with significant amounts of carbidizing elements such as cream or vanadium. The wear resistance of white cast irons is the main reason for using these cast irons in the industry. Malleable irons are also among the same group of irons.

### *Whitening of cast iron due to the penetration of tellurium*

In cases where mold covering materials containing tellurium or bismuth are used to improve the surface quality of gray cast iron parts, the thin layer on the surface of the part will turn into white cast iron (Figure 3).

**Figure 3:** Whitening of cast iron due to the penetration of tellurium.

## Results and Discussion

The result is that this steel is hypereutectoid, and according to the internal structure, i.e. the background of ferrite and coarse pearlite grains, we understand that it contains 0.4% carbon and 5% ferrite and 5% pearlite. Therefore, we conclude that for more pearlite in the structure of the metal, the percentage of carbon is also higher and because of the lower amount and percentage of carbon, the higher the amount of ferrite, and the darkness of the surface under the microscope is the reason for this claim. Cast irons are alloys of iron and carbon containing a number of other alloying elements such as silicon, manganese, sulfur, and phosphorus. The eutactic composition of cast irons includes graphite or iron carbide and austenite, which turns into other phases as the austenite phase continues to cool, and similarly, other important factors that determine the properties of cast irons are the amount, size, shape, and distribution of graphites. In other words, the control of the mentioned factors is the most important principle in the production of cast iron. The change of factors such as chemistry, germination method, solidification speed in cast irons, and also the effect of some alloy elements in critical amounts cause a great change in the type, shape, size, and distribution of graphites. The strength in gray cast irons is proportional to softer and weaker graphite bases. Given that, the strength in this type of cast irons is closer to the percentage of carbon because it depends on the eutectic composition, which is obtained using the equivalent carbon ratio from the following equation:

CE= (% +1/3 Csi%+D%)

If the amount of carbon is equal to 4.3%, the eutactic structure occupies the entire cross-sectional area, and if its amount is less than 4.3%, the mentioned cast iron has a pre-eutactic structure and contains eutactic structure, graphite, and iron and in the same way, in post-eutactic cast iron, large sheet graphites cause the cast iron to become softer and weaker. The structure of spherical graphites is observed in a cast iron cast in a sand mold. If the amount of magnesium required to spheroidize the graphites is low, and then the graphites will be obtained in a compact or pseudo-sheet form, in which case the cast iron will have less strength and flexibility than cast iron with spheroidal graphite, and finally, if the amount of magnesium is much less, in this case cast iron with sheet graphite will be obtained. It should be noted that in some cases, due to special reasons, it is practically tried to create graphites in cast iron in a compact or pseudo-sheet form. The size of spherical graphite, which affects the mechanical properties, is influenced by the following two main variables:

1. ***Cooling speed***: The cast sections that have thin sections are cooled at a higher speed, and as a result, the size of spherical graphites becomes smaller and their number increases in the cross section.
2. ***Silicon impregnation***: With silicon impregnation, the number of spherical graphites increases and the tendency to form carbides in thinner sections of the part decreases. In the same way, the number of spherical graphites also increases with the increase in the amount of nucleating agent.

By shining the right light on the polished and etched surface of a white cast iron sample, the macroscopic structure of primary dendritic and eutectic iron-carbide alloys can be distinguished from each other. The coarse structure of dendrites can be seen in the cross-section of a 15 mm diameter rod sample cast in a sand mold. In addition, if cobalt pore is used to grind the grains before casting, a finer structure of dendrites is obtained. As a result of irradiating the light obliquely, the dendrites will not be clearly visible. However, it is possible to see the granulation of the eutectic structure similar to the coarse form or similar to the fine form with signs of primary dendrites. The eutectic grain size in non-alloyed white cast iron is usually not subject to normal casting factors and is variable. The purpose of the standard specifications for ductile iron castings is to provide a set of information that both the designer and the caster can use with confidence that the designer can use this set to select a set of special features for their workshops. Convince the casting to use the plan. The use of technical specifications standard prevents the purchase of casting parts by the processor that the designer does not need. Because a standard casting states what meets the designer's needs, regardless of where or how the casting is produced. These specifications should be carefully selected and used, so as to be cost-effective enough to convince the designer that they adequately meet the designer's needs, without increasing unnecessary costs and unduly limiting the customer's choices. Among the duties of the designer and the molder to prevent the casting process from becoming complicated and increasing the costs, it is that both of them should be aware of the role of the factors that limit the properties. Furthermore, both of them should agree on a characteristic providing an optimal ratio of implementation costs. It is related to the designer to determine a set of the most suitable mechanical, physical, and chemical properties or dimensions for his design purposes. These properties are selected once and the foundry must guarantee that many parts are delivered, or raise the properties. The raw materials and manufacturing methods used by the foundry are to provide compatibility with the casting parts and are not normally limited by the designer, unless the part properties include such a recipe, or the designer, and foundry add such agree instructions. Such instructions should be wise because they increase costs almost constantly. ASTM has five standards for ductile iron. ASTM A536 is the most widely used in the field of ductile iron coating engineering. Other standards with austenite coating, which is special for ductile iron. ASTM defines a new specification of properties for wrought ductile iron that was published in 1990. ASTM J434 standard is usually used to determine the properties of ductile iron parts used in automobiles. To create a signal, a comprehensive system for the determination of metals and alloys is mentioned, which is obtained from the ASTM and ASA collaboration, which is called the United Numbering System. At one time this system was unknown. However, UNS currently has an acceptable value in North America and is used as a convenient means of summarizing the variety of specifications available.

## Conclusion

Non-alloy or low-alloy steels with about 0.4% carbon have low toughness when their structure is martensitic. Non-alloyed white cast irons, where most of the carbide in them is cementite, have been used for years due to their resistance to wear. However, in many cases, their use has not been satisfactory. The weakness of these cast irons is in their structure. The carbide phase forms a continuous network around the austenite grains and causes brittleness and cracking. The increase of an alloy element making carbon in the form of carbide other than cementite with more hardness and more favorable properties, reduces a certain amount of background carbon, and improves toughness and wear resistance at the same time. The most commonly used element is chromium and its carbide is mostly M7 C3. In crushers, the parts that are under wear should resist not only wear, but also dynamic stresses that can lead to sudden failures. The parts that are exposed to heavy stresses create a big problem and the part should have two contradictory properties together, which are wear resistance and toughness. Carbon is the most important factor that affects the wear resistance and toughness of iron alloys at the same time, but in the opposite direction. To obtain sufficient hardenability, it is enough to choose the right amount of alloying element for the specified thickness. The microscopic structure of this group of white cast irons includes discontinuous eutectic iron-chromium carbides and chromium-rich secondary carbides in a context of austenite or its transformation products. Also, with the help of heat treatment, austenite, martensite, bainite, or pearlite can be obtained.

## Disclosure statement

The author declare that they have no conflict of interest.

## Reference

[1]. A.K. Khairi, W. Li, S.H. Yeo, Y.S. Tong, M.N.B.A. Rahman, S. Motevalli, *International Journal of Academic Research in Business and Social Sciences*, **2022**, *12*, 262-278. [Crossref], [Google Scholar], [Publisher]

[2]. B. Ganavati, V.A. Kukareko, L.S. Tsybul'Skaya, S.S. Perevoznikov, *The Physics of Metals and Metallography*, **2014**, *115*, 1037-1045. [Crossref], [Google Scholar], [Publisher]

[3]. F. Rebout, A. Samimi, *Progress in Chemical and Biochemical Research*, **2022**, *5*, 196-217. [Crossref], [Publisher]

[4]. F. Rebout, *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, **2022**, *1*, 58-63. [Google Scholar], [Publisher]

[5]. N. Bahrami, S.A. Hosseini Almadani, S. Motevalli, F. Khoyeeni, *Iranian journal of educational sociology*, **2021**, *4*, 37-48. [Crossref], [Google Scholar], [Publisher]

[6]. M. Bagheri Sadr, A. Bozorgian, J. Chem. Rev., **2021**, 3, 66-82. [Crossref], [Google Scholar], [Publisher]

[7]. J. Mashhadizadeh, A. Bozorgian, A. Azimi, *Eurasian Chemical Communication*, **2020** *2*, 536-547 [Google Scholar], [Publisher], [Crossref]

[8]. S.S. Moayeripour, *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, **2022**, *1*, 40-56. [Crossref], [Google Scholar], [Publisher]

[9]. M. Moqadam, M. Rahmani, Z. Karimi, A. Naderifar, Procedia Engineering, **2012**, 42, 34-44 [Crossref], [Google Scholar], [Publisher]

[10]. Z Karimi, A. Rahbar-Kelishami, *Journal of Molecular Liquids*, **2022**, 368, Part B, 120751 [Crossref], [Google Scholar], [Publisher]

[11]. A. Samimi. *International Journal of Innovation and Applied Studies*, **2012**, *1*, 1-6. [Google Scholar], [Publisher]

[12]. A. Samimi, *Int. J. Sci. Eng. Invest. (IJSEI)*, **2012**, 1, 16-19. [Google Scholar], [Publisher]

[13]. S.S. Moayeripour, *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, **2022**, *1*, 138-149. [Google Scholar], [Publisher]