A Study of The Crystalline Structure of Ferrous Alloys (SAE 1018, 1020 and DF2) Subjected to Heat Treatments

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The main objective of this research project is to study the structure of three types of steels, SAE 1018, 1020 and DF2, which were subjected to heat treatments: quenching and tempering, the steels were divided into three groups; The first without any heat treatment, the second group was tempered and the third group was subjected to tempering and tempering, to differentiate how heat treatments influence the crystalline structure and mechanical properties of the steels studied and their hardness. Steels are of great importance because of their characteristics, which may vary depending on the percentage of carbon that exists in each of them, based on this percentage the mechanical behavior of steels, some of the characteristics that may vary are; hardness, mechanical resistance, or toughness, among others; As an example, a steel containing 0.4% carbon is going to be stronger than a steel that has a lower percentage of carbon. To appreciate the microstructure of these steels and their variations in terms of their structure, the samples of the steels were divided into three groups and subjected to different heat treatments already mentioned that were made at certain temperatures and residence times in an electric resistance furnace, after that the samples were prepared for visualization and structural comparison using a metallographic optical microscope.

Keywords: Structure, 1018, 1020, DF2, Heat treatments.

1. Introduction

Iron-carbon alloys (steels and castings) are the most important metal alloys of modern technology. By volume, the production of cast iron and steel exceeds by much more than 10 times the production of all other metals combined. The name is commonly given to iron-carbon alloys depending on their properties (Serrano, 2017).

The study of alloy structures is of great importance. The analysis of these structures allows to select the materials to incorporate in a design, the required properties, as well as the compatibility with other parts within an assembly. In the same way, it gives way to know the different types of materials available to take advantage of them in a much more efficient way, as well as to expand the panorama of mechanical engineering students in materials and their relevance in the industry (Sánchez, Medina Cervantes, Leyva Martínez, Peña Rivera, & López Velázquez, 2008).

It is impossible to raise the quality, reliability, and service time of machine parts without giving the metal materials the necessary properties, which is achieved with heat treatment.

In order to develop and apply rational heat treatment regimes, it is necessary to know the properties of the metal in its various structural states, that is, to know the relationships between the properties of the metal and its structure.

As far as pure iron-carbon alloys are concerned, the direct formation of graphite from the liquid is a rare phenomenon, except for a circumstance that favors it. The fact is that the liquid, in alloys with high carbon content (castings) in practice is not completely pure. In general, once the melting occurs, it is "cloudy" that is, it contains in a suspended state tiny particles of inclusions and impurities, among them are very small particles of graphite. In these begins the process of crystallization, they are the wall in which precipitate the carbon atoms forming the graphite crystal. In this case the work of constitution of the graphite germ may not be greater than that of formation of the cementite germ. Usually, even at a temperature below equilibrium (1147 ºC) it turns out to be kinetically possible the formation of graphite crystals (Torres Alpízar, Marín Brizuela, Suarez Torrelles, Llovera Seijas, & Muñoz Benaventa, 2014).

2. Objectives

2.1 General objective

Determine the crystalline structure of ferrous alloys (SAE 1018, 1020 and DF2) subjected to heat treatments and their mechanical behavior.

2.2 Specific objectives

- Compile bibliographic sources that address the general characteristics, research principles, methodologies and standards relevant to the analysis of steels.
- Establish the appropriate methodology for examining the structure formation of iron and carbon alloys during heating and cooling processes.
- Identify through laboratory tests the behavior of the structure of an iron-carbon alloy during heating and cooling in SAE 1018, 1020 and DF2 steels to determine the formation of its structure.

- Analyze the micrograph of the formation of the crystalline structure of metals and their behavior to adhesive wear.

3. Methodology

3.1 Hypotheses

The application of heat treatments on the following steels SAE 1018, 1020 and a special steel DF2 in an electric resistance furnace at a certain temperature and exposure time to each of these steels, allows to modify the structure, properties and mechanical characteristics. The results obtained by means of a metallographic optical microscope are able to expose the changes in the structures of the test specimens of the steels, before and after they are subjected to heat treatments. Using a durometer, the hardness of the steels studied is checked.

3.2 Level of research

The level of research carried out in the present work, is investigative, experimental and descriptive, because for the development of the work, the collection of information about the steels studied was carried out to expand the existing knowledge, and then, through practice, and under controlled conditions, the prophets of the three types of steels studied are tested, manipulating the study variables, to subsequently perform an analysis of the results and understanding of the conditions that directly influence the change of the structure and properties and mechanical characteristics of SAE 1018, 1020 and DF2 steels, subjected and not subjected to heat treatments, which is what is really intended to demonstrate through this research.

The present research is of qualitative correlational type, because, it is developed based on a qualitative metallographic study, which includes observing the structures and microconstituents by which the studied steels are formed, which can change according to the type of heat treatment that is applied and the metallographic process to which the samples are subjected.

3.3 Method

The present research uses the hypothetical deductive method, because it was based on a hypothesis and then draw conclusions based on that hypothesis, a hypothesis that is tested experimentally, starting with observation and ending with experimentation in the Foundry Laboratory to finally perform the analysis of results by metallographic optical microscope.

3.4 Techniques

The techniques that were used in the development of this research were:

- Bibliographic research, from the search of texts and all kinds of useful information for the better understanding and consequently development of the research.
- The observation, focuses on carefully observing the different variations that can occur in the structures of the steels studied, the way in which each type of heat treatment influences them, the temperature and the exposure time that was applied to the specimens, all this for the registration of the information and a subsequent analysis.
- Experimentation, through experimentation through practices in the Foundry

Laboratory and, microscopy to determine the structure of SAE 1018, 10290 and DF2 steels, demonstrating through the observation technique, if the statement of the hypothesis is approved or disapproved.

3.5 Resources

3.5.1 Human resources

- Student in charge of the research project.
- Teacher Tutor of this work.
- Engineers responsible for the Laboratories of the Mechanics Career.

3.5.2 Equipment and materials to be used

3.5.2.1 Electric resistance furnace

An electric oven is an equipment that has the ability to raise its temperature inside, so that the process of temperature elevation can be carried out, electrical energy is needed for its operation. The furnaces of resistances, need for their heating, energy of electrical type, and the heat generated, comes from the direct ohmic resistance of the electrical resistances that are in the furnace, which are heated by the Joule effect, these give heat to the material that is housed inside by the various forms of heat transmission.

Figure 1: Electric resistance furnace of the Mechanics career

The oven used in this practice is SAMO THERMAL Oven 8-18, which has a maximum temperature range of 1300 ° C, this is equipped with a digital control GENESIS LT1120 so it allows us to manipulate the heating time of the material that is inside and program for heat treatments.

3.5.2.2 Metallographic microscope

The metallographic microscope is a device that is basically constituted by an emitter of illumination, a glass or prism plane of reflection, the eyepiece and the objective.

Figure 2: Metallographic optical microscope of the OMAX Mechanical Race M83MPZ-C140U

This is characterized by the image that is displayed, which originates from the reflection of the light beams that affect the specimen. According to the product, the image can be observed by several magnifications; In the case of this research, the metallographic microscope, brand OMAX M83MPZ-C140U, is equipped with four lenses of magnification 4x, 10x, 40x and 100x, and includes a USB digital microscope camera of 14 MP that is capable of viewing the metallographic images on the computer screen and capturing them.

3.5.2.3 Durometer

The durometer is an instrument that is used to measure the hardness of different materials, this is made up of a spherical tip either diamond or tungsten, and in its body, a penetrating element that is the one that exerts the force on the material, and in this way, its hardness is measured.

Figure 3: PCE-2500N Mechanical Stroke Durometer

The digital durometer that is used in the present practice of this work, is brand PCE-2500N, and can measure the hardness in units HLD, HRC, HRB, HRA, HB, HV and HS, on materials such as steel, cast steel, steel alloy, stainless steel, cast iron, spheroidal graphite, aluminum alloys, brass, bronze and tin bronze.

3.6 Laboratory practice

To observe the structure of the steels studied in the present research, it is necessary to first go through a series of processes, which are discussed below:

Metallographic preparation of samples

Once the material has been obtained for the samples of the steels to be studied, which in this case are three, the material begins to be cut with the aim of acquiring three samples of each steel, obtaining a total of nine samples for the metallographic study.

Heat treatments of samples

The heat treatments are carried out in the Foundry Laboratory of the Mechanical Career in a controlled manner, using the electric resistance furnace, which is located in the same laboratory.

Each of the steels studied contains a different chemical composition and size, due to this, the calculation of the estimated time that the samples have to remain inside the electric resistance furnace at a certain temperature must be made according to the type of steel and the heat treatment that will be given. For these calculations, equations 2.1 and 2.2 are used, where the total heating time (τ_total) and the heating time to a given temperature (τ_c) are calculated. In all practices, the samples were placed in the central part of the electric resistance furnace, with the aim of achieving homogeneous heating on all faces of the samples with cylinder geometric characteristics.

SAE 1018 Steel

In the case of SAE 1018 steel, to determine the heating time through which the sample that will be heat treated has to pass, starting with a tempering and ending in a tempering, the calculation is as follows.

The following aspects must be considered: that the dimensional characteristic of the sample is given in mm, that the heating medium is gaseous, that the geometric relationship of the part is a cylinder and that the heating is everywhere of the part, the heating time to a given temperature is calculated as follows using equation 2.2:

$$\tau_c = 0{,}1 \cdot D_1 \cdot K_1 \cdot K_2 \cdot K_3$$

$$\tau_c = 0{,}1 \times 44 \times 0{,}5 \times 2 \times 1$$

$$\tau_c = 4{,}4$$

As the sample is an alloy steel (0.15-0.20 C; 0.6-0.90 Mn; 0.15-0.3 Si; 0.04 P; 0.05 S), the value of τ_p is 2 min. Then, using equation 2.1:

$$\tau_{total} = \tau_c + \tau_p$$

$$\tau_{total} = 4{,}4 + 2$$

$$\tau_{total} = 6{,}4 \text{ min} \approx 6 \text{ min}$$

Once calculated the time required for total heating of the pieces, two in this case, the samples are subjected to a tempering, in order that the perlite phase is transformed into austenite, which occurs above 727 ° C, and that at the same time the transformation of austenite into martensite occurs with the purpose of giving greater hardness to the pieces, which will be higher the more carbon content it has. So it is ready to heat the samples to a temperature of 790 ° C, and keep them for 20 min. After heating, the samples are cooled in oil that guarantees a controlled cooling and that gives uniformity of temperature throughout the piece.

After tempering, of the two samples subjected to tempering, only one sample is subjected to tempering, where heating is carried out at a temperature below 727 ° C, which is done at a temperature of 200 ° C for SAE 1018 steel, with a sustained of 15 min, with air cooling. The tempering is carried out in order to reduce the internal stresses in the iron-carbon alloy.

The simplified process of the SAE 1018 steel sample, which was quenched and tempered, is specified in Table 1.

SAE 1018 Steel				
Heat treatment	Temperature	Duration	Warm-up time	Cooling medium
Mettle	790°C	26 min	6 min	Oil
Tempering	200°C	21 min	6 min	Air

Table 1. Description of heat treatments for SAE 1018 steel sample

4. Analysis and results

The study of the structures of metals is of utmost importance and plays a fundamental role in determining the characteristics and applications that can be given to each type of metal, here is the importance that the constituents by which they are formed are studied and analyzed with accuracy and veracity. The optical microscope is an essential tool to perform a metallographic observation of steels, it also allows to differentiate the heat treatments to which the sample may have been subjected, specify defects and observe the mechanical properties that characterize steel, among other functions.

After completing the entire process that goes from obtaining the samples and the heat treatments to which they were subjected, mirror polishing and revelation of the structure through a chemical attack, the next step was the analysis of the samples of SAE 1018, 1020 and DF-2 steels, with and without heat treatments. This activity was developed in the metallographic microscope, using the 40X and 100X lenses, which allowed to observe the structures of the samples and evaluate the changes that occurred in their crystal structure.

The analysis of the samples gave the results presented below, they describe the different phases that are located in each steel that was subjected to heat treatments (tempering, quenching and tempering) and in commercial state (without heat treatment).

The state diagram characterizes the state of equilibrium of an alloy and that the lines of the diagram indicate the conditions of temperature and concentration of the transformations in equilibrium, that is, when the free energies of the phases that existed and of the new one that is formed are equal. The transformation is impossible at the equilibrium temperature of phases, since in this case nothing stimulates it: there is no advantage in reserve of free energy. For this reason the equilibrium diagram must be considered as that limit case in which at infinitely small rates of heating or cooling an infinitely small difference of the free energy levels is obtained than the coexisting phases and, consequently, the transformation is carried out at an infinitely small speed. But in reality the transformation temperatures that are observed when heating is done at a certain finite rate.

Crystallization in disequilibrium from a liquid solution is carried out without great subcooling and the determining feature of the alteration of the equilibrium conditions is the delay of diffusion in the solid phase; But in the liquid phase the diffusion processes have time to be fully realized. For secondary crystallization in disequilibrium, considerable subcooling, and the even greater delay of diffusion processes in the initial phase and in those in which they are formed are characteristic.

We will consider the most important case of decomposition of a solid solution with partial and variable solubility depending on temperature. By regulating the cooling rate, the degree of decomposition can be different, even neutralizing it. These supersaturated solutions are unstable. However, if the thermal mobility of the atoms in the subcooled solution is insufficient, the supersaturation state can be maintained for an indefinitely long time. Otherwise, over time there will be a gradual decomposition of the supersaturated solution with segregation of the phase that is in excess. This process will be accelerated if the temperature rises. The difference in structure at high temperature creates an important distinction in the technological and mechanical properties of alloys. The presence of eutectics makes the alloy not malleable. But at the same time the alloy with high carbon content has a low melting temperature and is used as a casting material.

Industrially produced carbon steel is an alloy of complex chemical composition. In addition to the base – iron, the content of which can range from the limits of 97.0 - 99.5%, there are in it many elements whose presence is due to the technological peculiarities of their production (manganese, silicon), the impossibility of totally excluding them from the metal (sulfur, phosphorus, oxygen, nitrogen, hydrogen) or chance circumstances (chromium, nickel, copper and others).

Steels differ mainly by the impurities they contain. Carbon greatly influences the properties of steel, even when its content varies negligibly. Therefore, when the content of all other possible impurities is small, the main element, by means of which the properties of a ferrous alloy can be varied, is carbon. Naturally, these alloys (when C<2%) are called carbon steels.

Influence of constant impurities on steel properties

Constant impurities of steels are considered manganese, silicon, phosphorus, sulfur and certain gases (hydrogen, nitrogen, oxygen), which in greater or lesser quantities are always present in the technical types of steel. The content of these elements is limited by the upper limits, in %: 0.8 Mn; o.05 P; 0.05 s. If its content is higher, steel should be considered alloyed, type in which these elements are specially introduced (hence the name alloy or special steels).

Sulfur should be considered as a harmful impurity of steel, the same as phosphorus, sulfur facilitates machinability by cutting.

Gases. Hydrogen, nitrogen and oxygen are found in steel in small amounts that depend on the manufacturing process. Hydrogen, nitrogen and oxygen can be found in the following forms: in various discontinuities (in the gaseous state), in the solid solution α and forming different compounds called non-metallic inclusions (nitrides and oxides). If there is a lot of hydrogen in the metal, this can cause very dangerous internal tears. The fragile nonmetallic inclusions that form nitrogen and oxygen worsen the properties of the metal.

According to the deoxidation procedure, the steel can be calmed (deoxidized with manganese, silicon and aluminum) or effervescent (deoxidized only with manganese). Thus, the chemical composition of effervescent steel differs from that of calming steel: the former contains almost no silicon (Si<0.05%), the latter contains its normal amount (0.12 – 0.3%). Effervescent steel is worse deoxidized and, therefore, contains more oxygen, its quality is lower than that of calming. An intermediate position for its quality occupies the so-called semi-calmed steel, deoxidized with manganese and aluminum, which begins to be used instead of effervescent and calming.

The variation of the shape during heat treatment, the fundamental purpose of which is to change the structure of the metal. The purpose of any heat treatment is to ensure that, by heating the metal to a certain temperature and then cooling it, the desired change in its structure occurs. The fundamental factors that influence heat treatment are temperature and time, so the regime of any heat treatment can be presented by means of a graph in coordinates t (temperature) and (τ time).

Quenching is a thermal operation consisting of heating to a temperature higher than the transformation temperature followed by sufficiently rapid cooling to obtain an unstable structural state of the alloy.

Tempering is a thermal operation in which the tempered alloy is heated to a temperature lower than the transformation temperature, to obtain a more stable structural state of the alloy.

During heat treatment there is a transformation that takes place in time, and it is impossible to establish the change it produces in time, if the state of the alloy is unknown. The status diagram shows what type of heat treatment an alloy can undergo and in which temperature ranges the treatment should be done. Tempering is heating above the critical pointA_{c3}, followed by rapid cooling. When cooling is slow, austenite decomposes into ferrite + cementite at the point. Tempering is a heating of the tempered steel below .$A_{r1}A_{c1}$

Four main transformations of steel

Austenite (A), solid solution of carbon in iron γ, ; martensite (M), solid solution of carbon in iron α, ; perlite (P), eutectoid mixture of ferrite and carbide, which are formed simultaneously.$F_{\gamma}(C)F_{\alpha}(C)F_{\alpha} + F_3C$

In the heat treatment of steel, four main transformations are observed:

- The transformation of perlite into austenite, which passes above the point, at a temperature higher than that of the stable austenite-perlite equilibrium; At these temperatures, of the three fundamental structures, austenite has the minimum free energy.A_1

$F_{\alpha} + F_3C \rightarrow F_{\gamma}(C)$ or $P \rightarrow A$

- The transformation of austenite into perlite, which develops below :A_1

$F_{\gamma}(C) \rightarrow F_{\alpha} + F_3C$ or $A \rightarrow P$

- The transformation of austenite into martensite:

$F_{\gamma}(C) \rightarrow F_{\alpha}(C)$ or $A \rightarrow M$

This transformation is observed below the temperature of the metastable austenite-martensite equilibrium. A is more stable perlite, but the work required for the formation of martensite from austenite is less than that required for the formation of perlite; Therefore, below , the formation of perlite (mixture of ferrite and carbide) from austenite can only be effected as a result of the transformation of austenite into martensite and then martensite into perlite. Therefore, the austenite-martensitic transformation is, in this case, intermediate in the process of transition from austenite to perlite.$(T_0)T_0T_0$

- The transformation of martensite into perlite or more accurately, into a mixture of ferrite and carbide:

$F_{\alpha}(C) \rightarrow F_{\alpha} + F_3C$ or $M \rightarrow P$

This transformation takes place at all temperatures, since at all temperatures the free energy of martensite is greater than that of perlite.

Formation of austenite

The transformation of perlite into austenite in full accordance with the Fe – C state diagram can only be carried out if heating is very slow. Under normal heating conditions, the transformation is delayed and overheating is obtained, i.e. the transformation only occurs at temperatures somewhat higher than those indicated in the Fe – C diagram.

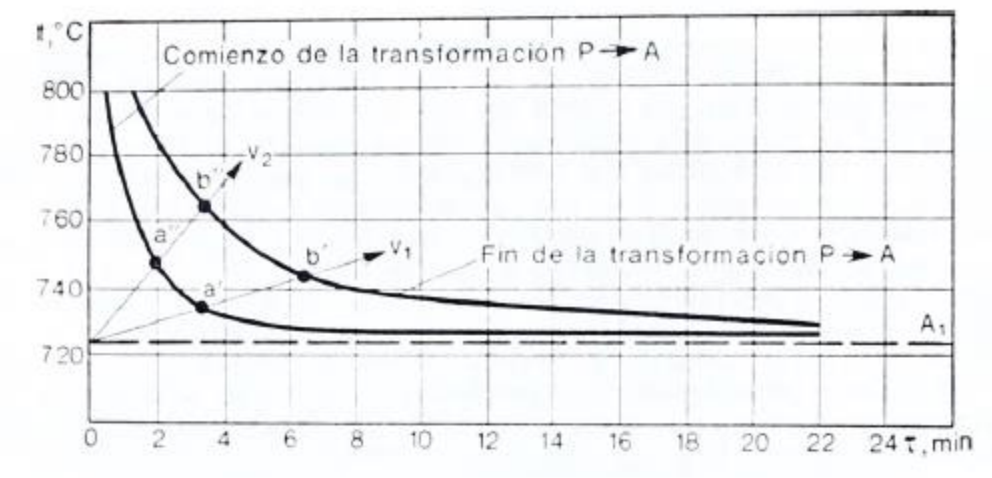


Figure 4. Transformation of perlite (P) into austenite (A) at constant temperature

Source: I. L & M. E Blanter. Steel with 0.86% C.

Perlite superheated above the critical point is transformed, at different rates depending on the degree of overheating, into austenite. For example, if the temperature is maintained at 780°C, the perlite + austenite transformation is completed in 2 min, and at 740 °C, in 8 min.

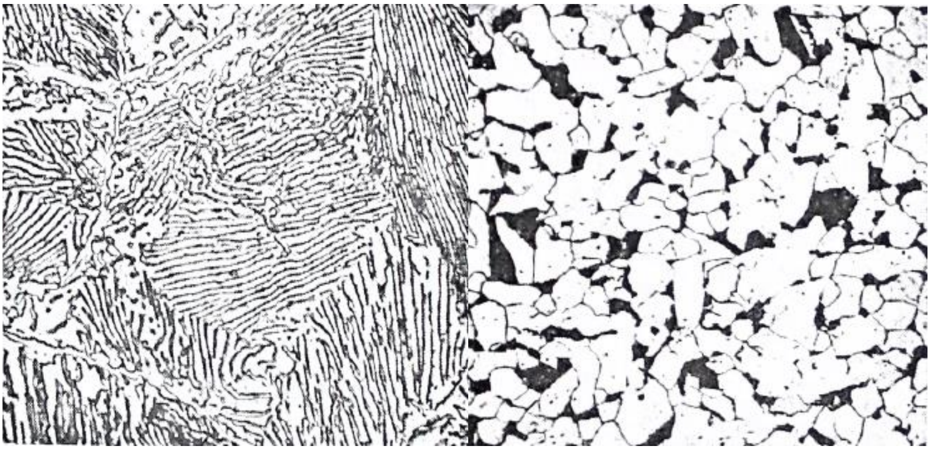

(a) (b)

Figure 5. Structure of Perlite and Hypoeutectoid Steel

Perlite, sorbit and troostite are structures of the same nature (ferrite + cementite) that differ from each other by the degree of dispersion of ferrite and cementite. Perlithic structures can be of two types: granular (in which cementite is in the form of granites) or laminar (in which it is in the form of sheets).

Homogeneous austenite is always transformed into laminar perlite. Therefore, heating to high temperature, which creates the conditions for a more homogeneous structure to form, favors the appearance of laminar structures. Inhomogeneous austenite gives, whatever the degrees of subcooling, granular perlite, therefore heating to a low temperature (for hypereutectoid steel, below A_c3, leads during cooling to granular perlite formation. Probably, the particles that remain undissolved in austenite, being additional crystallization centers, favor the formation of granular cementite.

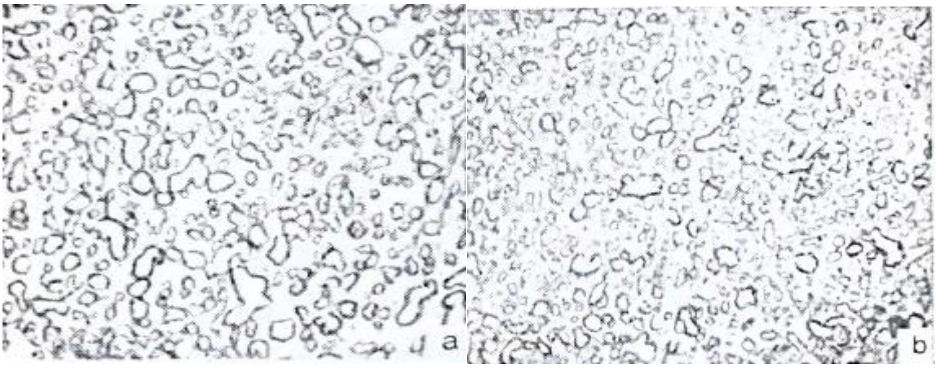


Figure 6. Granular perlite obtained from heating

Source: I. L & M. E Blanter .́Granular perlite in steel with 1.2% C, obtained as a result of heating to 780 °C (i.e. below A_c3 and isothermal transformation to 710 °C (a) and 670 °C (b). x800

In hypoeutectoid steels the transformation of austenite begins with the formation of ferrite and the carbon enrichment of the remaining γ solution; that of the hypereutectoids, with the precipitation of cementite and the carbon depletion of austenite. Under equilibrium conditions the decomposition of austenite into ferrite and cementite (i.e. pearlitic transformation) begins when the carbon content in austenite remaining after precipitating ferrite or excessive cementite is that corresponding to point S (0.8%)

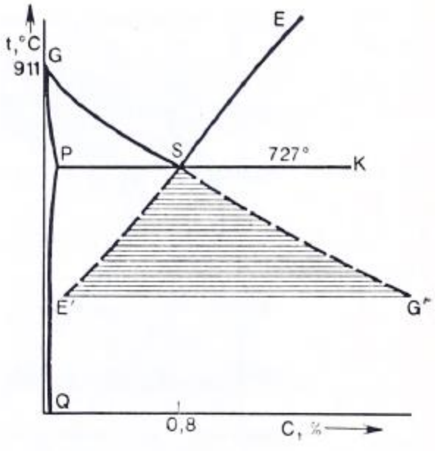


Figure 7. Composition of eutectoid depending on the degree of cooling

Source: I. L & M. E Blanter. Composition of eutectoid depending on the degree of subcooling below equilibrium temperature A.

If the cooling is done with a much lower rate than the critical one, austenite, in the upper region of temperatures, is only partially transformed, and the structure will be constituted by the products of the transformation in that region (troostite) and by martensite.

Martensitic transformation

If austenite is subcooled to temperatures at which the lattice γ, despite the presence of dissolved carbon in it, is unstable, but the rate of diffusion of carbon, due to low temperatures, is so small that it cannot be taken into account, the network is restructured without precipitating carbon:

F_γ (C)→F_α (C)

This transformation, by its mechanism and by the nature of the resulting products, differs from the eutectoid decomposition of austenite studied above. In the austenite-pearlitic transformation the leading role is played by carbon diffusion and this transformation should be called diffusive.

In the austenite-martensitic transformation only a restructuring of the network occurs, without varying the concentration of the phases that react, This transformation is without diffusion. Martensite in steel is a supersaturated solid solution of carbon in iron α whose concentration is equal to that of initial austenite. As the solubility of carbon in the α phase is only equal to 0.01% or less, martensite is a supersaturated solid solution.

Further heating above 200°C leads to a different transformation that causes the steel to expand. This second transformation (stage) in tempering covers the temperature range of 200 – 300 °C. In this interval the residual austenite is transformed into a heterogeneous mixture formed by supersaturated α solution and carbide. In other words, in this transformation the residual austenite becomes tempered martensite. This transformation is diffusive and by its nature resembles the bainite of primary austenite. At the end of the second transformation, i.e. at 300°C, the solid solution α still contains about 0.15 – 0.20% C; The compression that begins if the temperature continues to rise.

In the third transformation (stage) in the tempering there is a series of variations leading to the elimination of internal stresses and conversions of carbides. At 400°C the third transformation ends and the steel consists of ferrite and cementite. If the temperature continues to increase, coagulation of the ferrite and cementite particles occurs, which can be easily observed in the microstructure at high magnifications.

4.1 Microstructures of SAE 1018 steel and changes in its hardness

4.1.1 Sample of SAE 1018 steel without heat treatment

Heat treatments directly influence the mechanical properties of metals, since these do not only depend on the chemical composition of the material. In the case of SAE 1018 steel, in practice, the heat treatments of tempering, quenching and tempering were applied, obtaining the microstructures shown in table 13 and 14, and without heat treatment shown in table 12, it was performed with two magnifications (40x, 100x), its structure was captured after its visualization in the metallographic microscope.

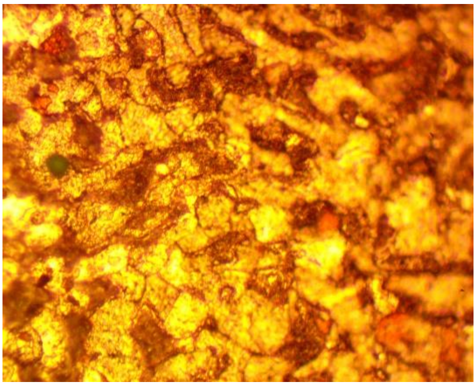
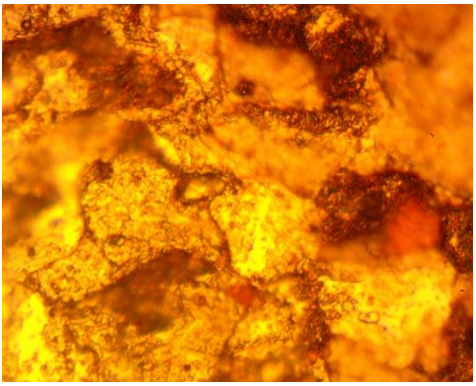
SAE 1018 Steel	
Heat treatment: None	
Microstructures	
	
40x	100x
Localized phases	
Ferrite	Cementite

Table 2. SAE 1018 steel microstructures without heat treatment

4.1.2 Sample of SAE 1018 heat-treated steel: Hardening

Table 3 presents the microstructures of the sample of SAE 1018 steel, heat-treated with tempering, with two types of lenses (40x and 100x), and phases obtained.

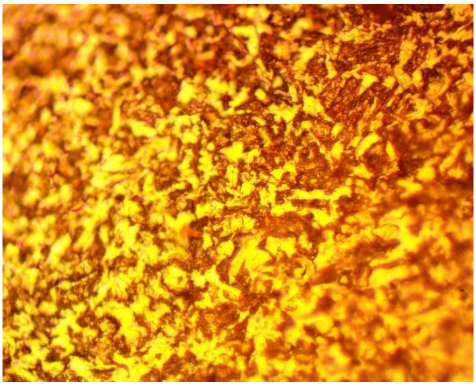
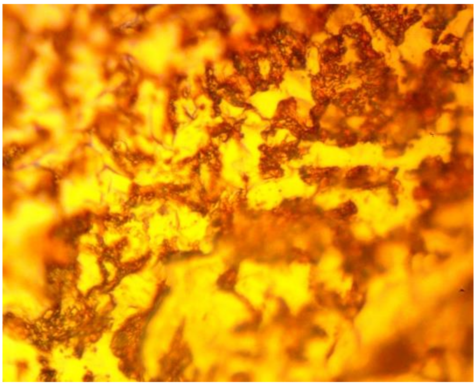
SAE 1018 Steel	
Heat treatment: Tempering	
Microstructures	
	
40x	100x
Localized phases	
Martensite	Cementite

Table 3. SAE 1018 steel microstructures, resulting from Tempering heat treatment

4.1.3 Sample of SAE 1018 heat-treated steel: Tempering and Tempering

Table 4 presents the microstructures of the SAE 1018 steel sample, heat-treated with hardening and tempering, with two types of lenses (40x and 100x), and phases obtained.

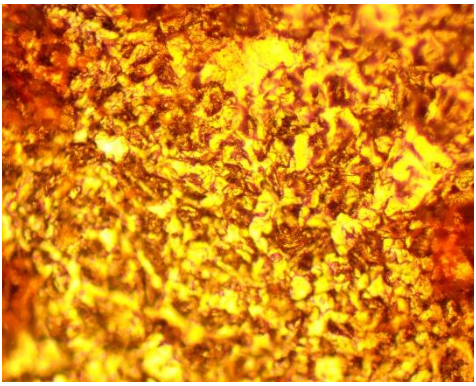
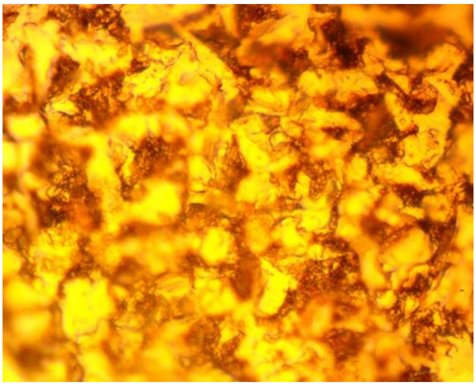
SAE 1018 Steel	
Heat treatment: Tempering and tempering	
Microstructures	
	
40x	100x
Localized phases	
Ferrite	Martensite

Table 4: Microstructures of SAE 1018 steel, result of Tempering and Tempering heat treatment

The following figure shows the cooling diagram to which SAE 1018 steel was subjected.

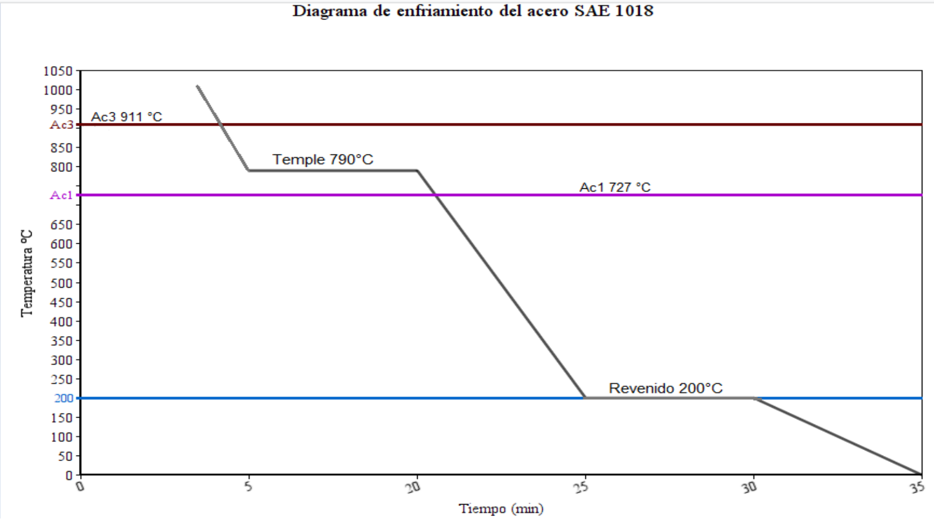


Figure 8. SAE 1018 Steel Cooling Diagram

The hardening of SAE 1018 steel aims to increase its hardness and resistance to breakage. Due to tempering, austenite is transformed into a metastable structure, martensite. The latter is a supersaturated solid solution of carbon in iron α. The carbon content in martensite is the same as in initial austenite. Martensite is an oriented structure with a high hardness in HB 130. The results of the hardening depend a lot on the choice of the heating temperature for the tempering. If the temperature of the hypoeutectoid 1018 steel is below 727 ° C A_c1, there will be no phase transformations and its structure will be ferrite + perlite, however, the 1018 steel was heated to a temperature of 790 ° C with a slow cooling in oil the austenite was transformed into martensite and the 1018 steel acquired the ferrite + martensite structure.

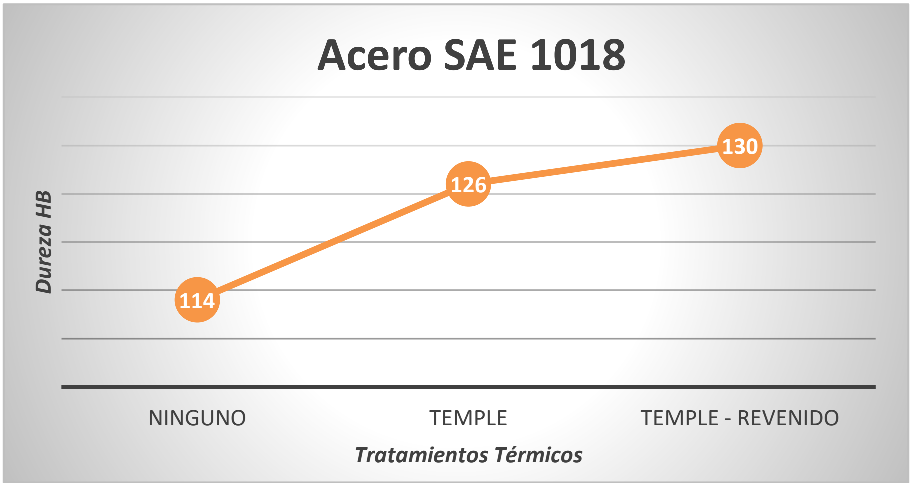


Figure 9. HB hardness graph in SAE 1018 steel

After the application of the treatments, the change acquired by the specimen with complete heat treatment compared to the specimen in commercial state (initial), 114 HB; 126 HB and 130 HB.

4.2 Microstructure of SAE 1020 steel and changes in its hardness

4.2.1 Sample of SAE 1020 steel without heat treatment

The microstructures of SAE 1020 steel in commercial state, that is, without heat treatment, as a result of the visualization that was carried out in the metallographic optical microscope, the results are shown in table 5, with two different lens measurements (40x and 100x), including the phases that are present in this steel.

SAE 1020 Steel

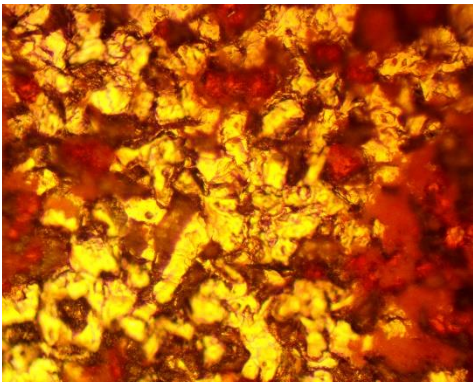
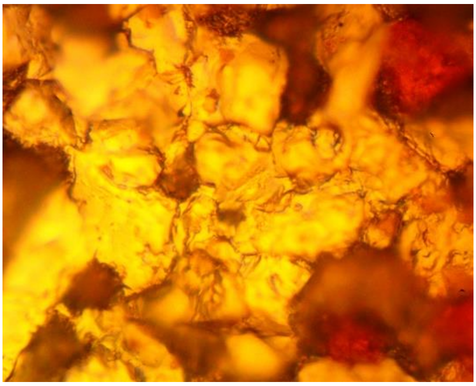
Heat treatment: None	
Microstructures	
	
40x	100x
Localized phases	
Ferrite	Cementite

Table 5. Microstructure of SAE 1020 steel without heat treatment

4.2.2 Sample of SAE 1020 heat-treated steel: Hardening

In Table 6. The micrographs resulting from the visualization in the metallographic optical microscope of the SAE1020 steel are shown, after being subjected to a heat treatment by tempering, with two measurements of the microscope lens (40x and 100x), also including the phases that are present in this steel.

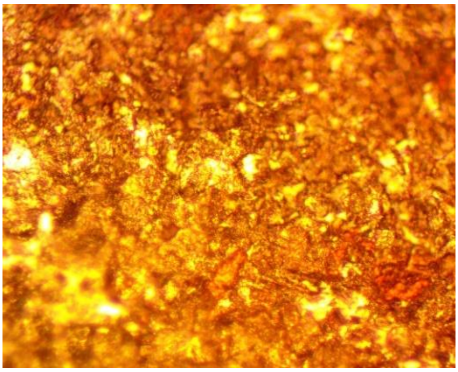
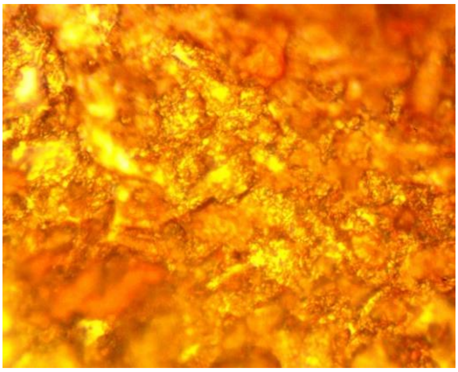
SAE 1020 Steel	
Heat treatment: Tempering	
Microstructures	
	
40x	100x
Localized phases	
Martensite	Cementite

Table 6. SAE 1020 steel microstructures with heat treatment of Hardening

4.2.3 Sample of SAE 1020 heat-treated steel: Tempering and Tempering

Table 7. The micrographs resulting from the visualization in the metallographic optical microscope of the SAE1020 steel are shown, after being subjected to a heat treatment by quenching and tempering, with two microscope lens measurements (40x and 100x), also including the phases that are present in this steel.

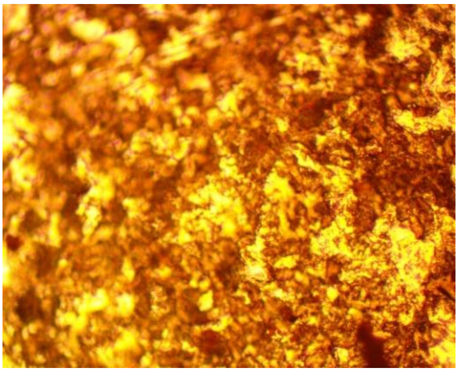
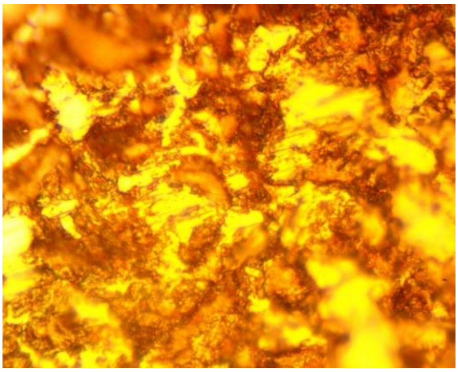
SAE 1020 Steel	
Heat treatment: Tempering and tempering	
Microstructures	
	
40x	100x
Localized phases	
Ferrite	Martensite

Table 7. SAE 1020 steel microstructures with quenching and tempering heat treatment

In order to carry out the tribometer tests, hardened AISI-O1 (DF2) steel specimens were used; the variables manipulated in the test were rotation speeds and time, as detailed in Table 8:

Angular velocity and time			
Rpm	200	400	600
Minute	20	60	100

Table 8. Rpm and test minutes

The programming with the WLP software (WEG LADER PROGRAM) will provide 5 types of variables as shown in Table 9:

Variables Weg Lader Program	
Indicator	Designation
🟦	Time elapsed (min)
🟥	Temperature (°K)
🟪	Power (Watt)
🟪	Frequency (Hertz)
🟩	Angular velocity (RPM)

Table 9. WLC program variables

To determine the behavior of the DF2 steel specimens, the equations in Table 10 were used:

Equations	
Denomination	Formula
Gravimetric wear intensity	$\mathrm{Ig} = \frac{g}{sf * An}$
Test speed	$v = \frac{\pi * d * n}{6000}$
Friction travel	$sf = v * t$
Contact area radius	$\rho = 0{,}909 \sqrt[3]{\theta z * r * N}$
Sum of modulus of elasticity of the materials in contact	$\theta z = \frac{1 - U_1^2}{E_1} + \frac{1 - U_2^2}{E_2}$
Nominal area	$An = \pi * \rho^2$

Table 10. Wear test procedure equations

Table 11 summarizes the results of mass loss by application of the adhesive wear test.

Results				
Before rehearsal		After the rehearsal		RPM
Mobile Probe (gr)	Fixed probe (gr)	Mobile Probe (gr)	Fixed probe (gr)	
84,18	87,66	84,16	87,64	200
84,18	87,66	84,11	87,60	400
84,18	87,66	84,03	87,57	600

Table 11. Loss of mass of specimens.

Table 12 summarizes the results of the calculations performed to obtain the mechanical properties associated with the adhesive test.

Results				
RPM	Gravimetric data (mgr)	Friction travel (mm)	Speed (m/s)	Sum of the modulus of elasticity (mm^2/N)
200	20	2260080	1,256	$8{,}7922x10^{-6}$
400	70	9047520	2,51	$8{,}7922x10^{-6}$
600	180	27143360	3,76	$8{,}7922x10^{-6}$

Table 12. Calculation of specimen test procedure.

5. Conclusions and recommendations

Conclusions

Through the bibliographic review of the steels studied, it is evident that the special steels SAE 1018, 1020 and DF-2 are considered hypoeutectoid steels due to their low carbon content. These steels are widely used in the manufacture of structural parts or medium-strength machinery due to their composition. SAE 1018 and 1020 steels contain significant amounts of Mn and Si, which gives them high weldability and toughness. On the other hand, DF-2 steel is highly alloyed, with contents of Mn, Cr, W, V and Si, and its wear resistance improves with the improvement of Cr and W. Furthermore, through research, it has been possible to know the different heat treatments that can be applied to these steels in order to improve their properties and how these treatments influence their performance during their use. By virtue of what was studied, heat treatments were carried out on the specimens of each type of steel studied in the facilities of the Foundry Laboratory of the Mechanical Career, thanks to the use of an electric resistance furnace, the heat treatments applied were tempered and tempered for SAE 1018 alloy steels, 1020 and DF-2. The heat treatments mentioned were executed based on the chemical composition of each of the samples, and depending on the expected results in the change of its microstructure, the heat treatments were carried out at certain temperatures and heating time which were previously calculated.

To reach a conclusion, the OMAX M83MPZ-C140U metallographic optical microscope was used, in which it was possible to visualize the micrographs of the treated and non-heat-treated samples, managing to verify the changes experienced by the SAE 1018, 1020 and DF-2 steels, and the improvements they show after the application of a quenching and tempering. In the micrographs you can see the presence of ferrite and cementite when the steels are in a commercial state, and then, after applying a temper in them (at temperatures higher than the phase transformation) a change in their phases is observed in which the cementite is transformed into martensite, to complement the operation a tempering was executed in order to guarantee a structural state with greater stability (at lower temperatures). to the transformation), ferrite and martensite are generally obtained in the results, these constituents generate a considerable increase in their hardness.

Faced with the microstructural results obtained in the specimens, it is revealed that, after the application of a tempering with rapid cooling in water and oil and a tempering to the air, the microstructures change and the phases originate; Ferrite and martensite, constituents of the different characteristics of ferrite and cementite that were visualized in the commercial state of the samples. As for the hardness of the steels on which this research is based, they increase their hardness in a considerable proportion thanks to the application of heat treatments under appropriate conditions, this is a mechanical property that was verified after the performance of a hardness test executed on the samples through a digital durometer, which states that SAE 1018 steel adopts a hardness ranging from 114 HB to 130 HB; SAE 1020 steel, increases its hardness from 150 HB to 145 HB; and the special DF-2, with a hardness of 76 HB after heat treatment reaches a value of up to 130 HB.

The adhesive wear tests allow determining that the level of mass loss for both specimens (fixed and mobile) tends to increase as the revolutions increase. Considering the test that presented higher gravimetric wear, it is concluded that DF2 steel as a cutting and shearing tool has a very good resistance to adhesive wear in medium exploitation conditions.

Recommendations

For the correct use or operation of the samples it is necessary to have knowledge of the chemical -To ensure satisfactory results in the investigation, it is essential to obtain knowledge about the chemical composition of each sample and its relationship to the objectives of the study. It is necessary to identify the components of the steel and the possible transformations that can occur when exposed to different temperatures, both above and below the phase transformation line. In addition, the heat treatments to which they can be subjected must be considered, taking into account the specific applications of each type of steel.

The shape, geometry and size of the sample (such as sphere, cylinder, parallelepiped or sheet), as well as its composition and the heating method used (such as gases, salts or molten metals), are crucial aspects to consider. These characteristics depend on the time required to heat the sample to a specific temperature inside the furnace, and this time must be calculated in advance to ensure that the desired phase is obtained in the samples.

Adequate polishing of the sample surface is essential to obtain optimum quality. This implies achieving a reflective surface, which allows revealing the microstructure by means of an appropriate chemical attack. This procedure ensures visualization of the microstructure through an OMAX M83MPZ-C140U metallographic optical microscope, which is used to perform the corresponding analysis.

It is essential to carry out an accurate visualization and identification of the phase constituents present in the resulting micrographs of each sample. The mechanical properties of materials are determined by the types of constituents present in the steel, and these properties are key to determining the applications in which each steel can perform based on its composition.

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