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PROBLEMS IN HEAT TREATMENT OF P20 ALLOY STEEL

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Abstract. *The development of new materials brings benefits to industry, mainly the mechanical, that uses alloy of metals more adequate to its finalities. These new materials, however, may be exposed to unknown problems, that must be researched and solved. The P20 steel is an alloy developed to injection molds to materials with low temperature of fusion, like plastics. However, in a specific application in industry, were found some cracks in molds after its heat treatment. This work has the objective to investigate by metallographic testing, possible deviations on heat treatment procedures in this application and how it may affect the material microstructure, allowing the occurrence of cracks and other deviations, in order to minimize or solve these problems. As a result of the search is concluded that use of inappropriate cooling medium can be the cause of the occurrence of crack and it is recommended to use a milder means of cooling, such as oil, for this purpose.*

Keywords: *P20 Alloy, Heat Treatment, Microstructure*

1. INTRODUCTION

The development of methods for materials extraction from nature, increasing the capacity of modification and manipulation of known materials or combination of existing materials to form other, in recent years has enabled a large increase the number of new materials, more suited to applications to which they are subjected as expose Van Vlack (1992), and among them, the P20 alloy steel.

A survey was conducted in a private company in the state of São Paulo that uses P20 alloy steel in their manufacturing processes, observing the appearance of cracks in various molds machined by the company, when subjected to heat treatment and subsequent rectification, for its surface finish. This work is the detailed analysis of the compounds and processes performed in this metal, aiming to solve the appearance of surface cracks in these matrices after heat treatment processes.

These cracks were small and almost imperceptible, but entailed leakage of injected material and loss of quality of the final product.

To remedy these deviations, we proposed a joint effort between the company and the SENAI College of Technology "Antonio Adolpho Lobbe" in order to find causes and possible solutions to the problem. For its implementation were used equipment from other institutions, both educational and companies.

The study is an applied research, selecting some steel samples P20 provided by the company. Treatment was performed with some small deviations in temperature and cooling type. Thus, were analyzed hardness and microstructure of the material, looking for differences between samples and pointing which cases are more prone to the appearance of cracks or defects in the material caused by the treatment.

In the literature review were searched topics on iron, steel P20 and their properties are presented on section below, then is presented the research methodology, some results and finally the conclusions found during this work.

2. THEORY

2.1 Iron and steel constitutents

Remy et al (2002) tell that iron, main component of steel, is an element whose crystalline shape is cubic crystalline characterized by the fact that element present allotropy or polymorphism phenomenon, namely the ability to have different crystal forms, which are body-centered cubic (BCC) and the face-centered cubic (FCCs), depending on its temperature. According to the authors, the iron atom takes two different forms, as shown in Fig. 1:

- Body-centered cubic iron: iron atoms has at each corner of the cube and one atom in its center corresponds to the allotropic forms "delta and alpha";
- Face-centered cubic iron: iron atoms has the vertices and centers of the faces of the cube corresponds to form "gamma".

The delta form appears when the iron solidifies and remains until the temperature of 1394°C. At this instant, therefore, atomic force, there is a rearrangement of the atoms in the lattice which passes cubic gamma allotrope, which remains until the temperature of 912°C.

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At this temperature, there was redistribution of iron atoms in the cubic lattice, which returns to the body-centered cubic shape corresponding to the shape allotropic alpha, which persists even at ambient temperature.

Allotropic transformations cause energy changes during cooling and during heating of iron, as in solidification or its fusion.

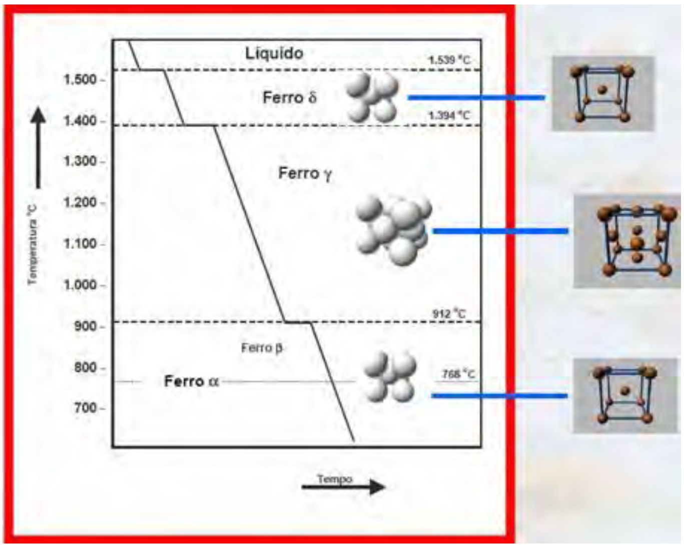

Figure 1. Different atomic arrangements for iron. Font: Chiaverini (2005)

According Chiaverini (2005), the constituents present in steel are:

- Austenite: consists of an interstitial solid solution of carbon (up to 2.11%) in the iron FCC. In carbon steels and low alloy steels is stable only above 727°C. Features mechanical strength around 150 MPa and high ductility and toughness. The austenite is not magnetic;
- Ferrite: consists of an interstitial solid solution of carbon (up to 0.022%) in iron BCC. The ferrite is magnetic and has a low mechanical strength, about 300 MPa, excellent toughness and high ductility;
- Cementite: naming iron carbide Fe_3C containing 6.7% carbon and orthorhombic crystal structure. Has high hardness, low strength, low ductility and low toughness;
- Pearlite: This involves the mechanical mixing of the ferrite phase (88.5% mass) and cementite (11.5% mass) formed by the combined growth of these phases. Has properties intermediate between ferrite and cementite depending on the size and spacing of cementite lamellae;
- Martensite: is a metastable phase consisting of iron that is supersaturated with carbon, which is the product of a transformation without diffusion (non-thermal) austenite. It is formed when iron-carbon alloys austenitized are rapidly cooled (as in tempering heat treatment). It is a single-phase structure (BCT), body-centered tetragonal, because it is in equilibrium, resulting from a transformation without austenite diffusion. The hardness of martensite depends on the carbon content and alloying elements of steel, higher carbon content will result in a higher hardness of martensite;
- Bainite: the constituent which may be formed when the austenite is cooled rapidly to a certain temperature, usually in the range between 200 and 400°C and maintained there. Bainite is a dispersion of submicroscopic carbides in ah alpha matrix highly deformed which contains than 0.02% carbon.

2.2 P20 steel alloy

The P20 steel is a special alloy, formed by the composition illustrated in Tab. 1, and widely used in the manufacture of injection molds materials with low melting point, such as plastics, according to Chiaverini (2005). The main motive is its peculiar properties, as low hardness which is machined and high hardness after heat treated. These characteristics, combined with its good machinability, low weathering and melting point much higher than that of plastic, turns this alloy ideal to this application.

Table 1. P20 Alloy components.

Element	C	Mn	Si	Cr	Mo	Ni	P	S
% mass	0.35-0.45	1.30-1.60	0.20-0.40	1.80-2.10	0.15-0.25	0.90-1.20	0.03	0.03

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3. METHODOLOGY

The methodology of the work is given in order to submit samples of the alloy in question to different conditions of tempering and annealing.

These samples then were measured in a hardness test which consists in penetration resistance or permanent deformation of the material surface, where the scale used for the test was Rockwell C, suitable for all types of hard steels, as shown Souza (1982). After this process was performed metallographic analysis, the principle of which is microscopically analyzing the internal structure of the material and its physical properties, classifying them according Rohde (2010).

The materials used and their sources were as follows:

- Samples of Steel P20, provided by the company in question, showed in Fig. 2;
- COEL Heat treatment oven. It was used the oven from laboratory of a large company in the region, specialized in machining of several different types of alloy steel;
- Durometer REICHERTER STIEFELMAYER UH 250, available at the SENAI College of Technology “Antonio Adolpho Lobbe” in São Carlos - SP;
- Optical Microscope Axiovert 100 A – Zeiss/Image pro-plus used in SENAI Technical School “Nadir Dias de Figueiredo” in Osasco – SP.

Figure 2. Samples used for heat treatment

4. RESULTS

Results were obtained by the heat treatment and the hardness test, shown in Tab. 2. Each sample was subjected to tempering for about 20 minutes of heating at different cooling conditions and annealing for an hour and a half, when it was the case. Subsequently hardness was measured on the Rockwell scale C in each sample, also shown in the Tab. 2.

The first sample, numbered as sample 0, was considered the baseline, because suffered heat treatment process according to recommended by bibliography, Rohde (2010).

Table 2. Treatment for each sample and hardness measured

Sample	Tempering [°C]	Cooling	Annealing [°C]	Hardness HRC
0	830	Oil	200	27.8
1	830	Oil	N/A	31.8
2	700	Oil	200	33.0
3	1000	Oil	200	47.8
4	830	Air	200	41.1
5	830	Water	200	41.2

After treatment, a metallographic analysis was performed on each sample using an optical microscope, and the microstructures observed in each case are shown in following figures, with its composition.

The samples of Fig. 3, Fig. 4 and Fig. 5 showed the same structure consists of ferrite and pearlite, since the cooling mode is identical and the rate of temperature increase was small, the influence of the differences between them affected only the arrangement of the components.

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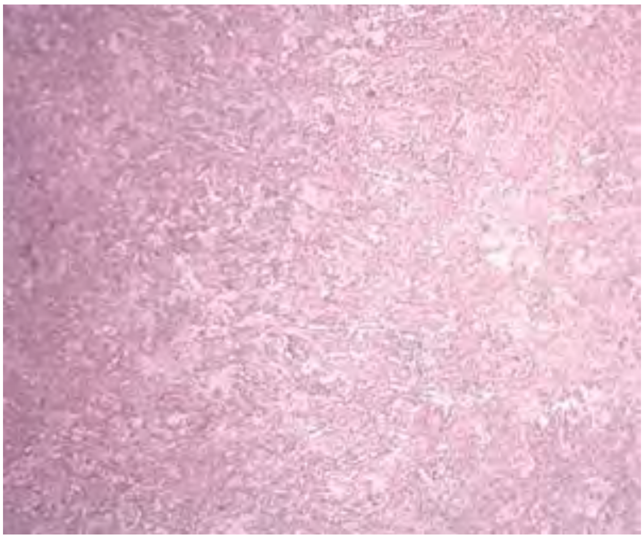

Figure 3. Sample without heat treating microstructure

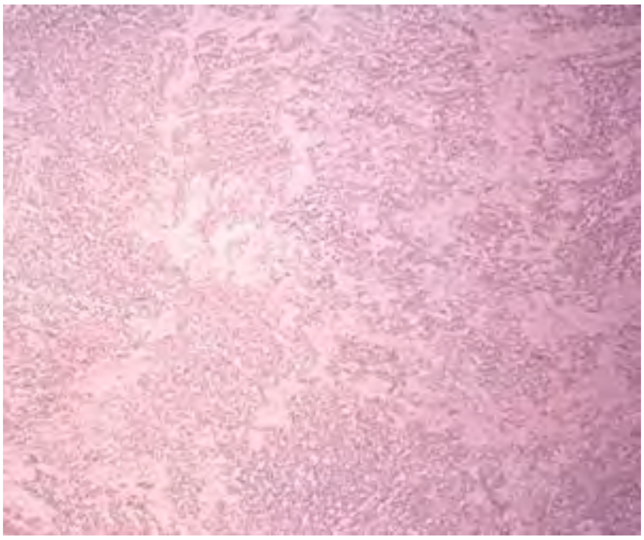

Figure 4. Sample 0 microstructure

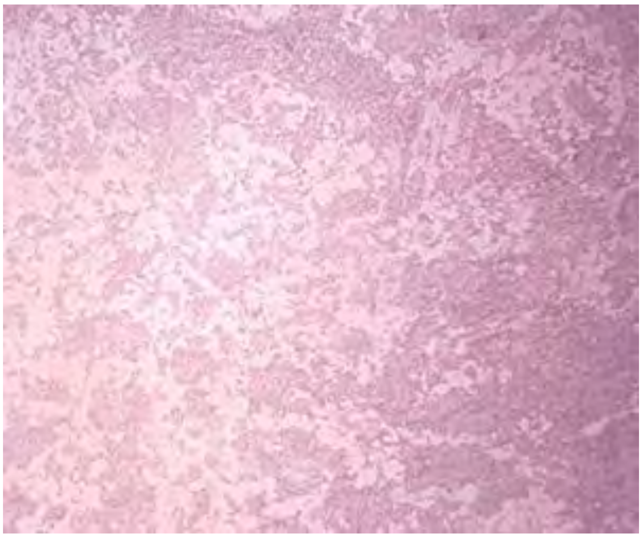

Figure 5. Sample 1 microstructure

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Changing the tempering temperature to a smaller value, the sample showed on Fig. 6 presents structure composed of ferrite and martensite with a slight presence of carbides.

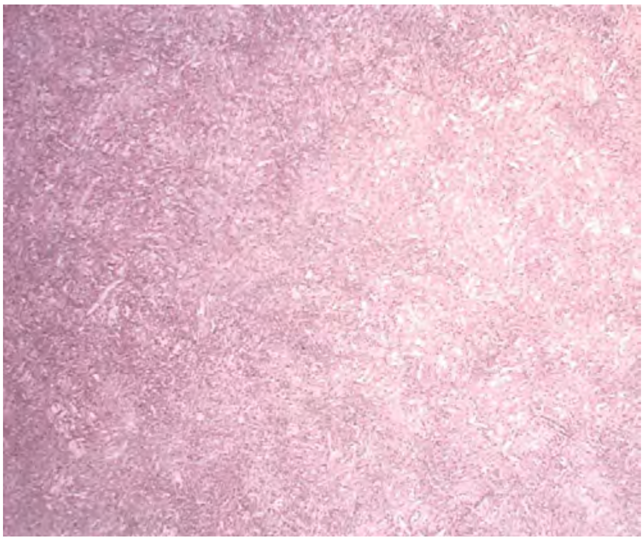

Figure 6. Sample 2 microstructure

With higher temperature during tempering, the result in structure is the presence of martensite and small areas of fine pearlite with strong presence of sulfides, as shown in Fig. 7.

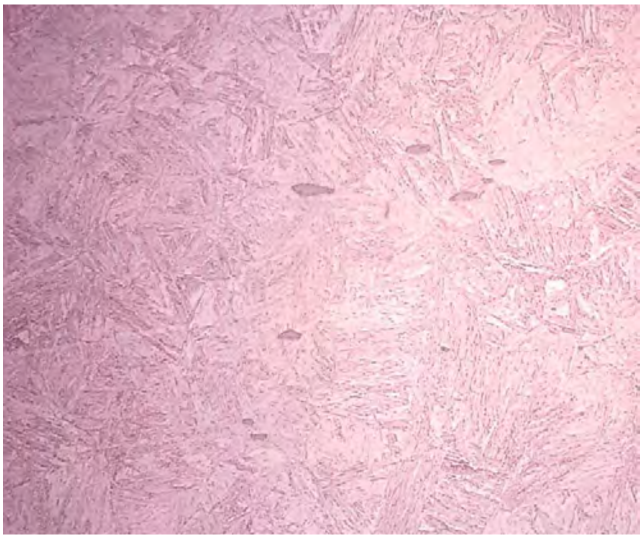

Figure 7. Sample 3 microstructure

In samples 4 and 5, the cooling method were varied, at first of them, the heating was cooled on fresh air and the sample shown in Fig. 8 presents a structure consisting of bainite and carbides.

The sample of Fig. 9, cooled using water, obtained a structure consisting of martensite and carbides with small traces of retained austenite.

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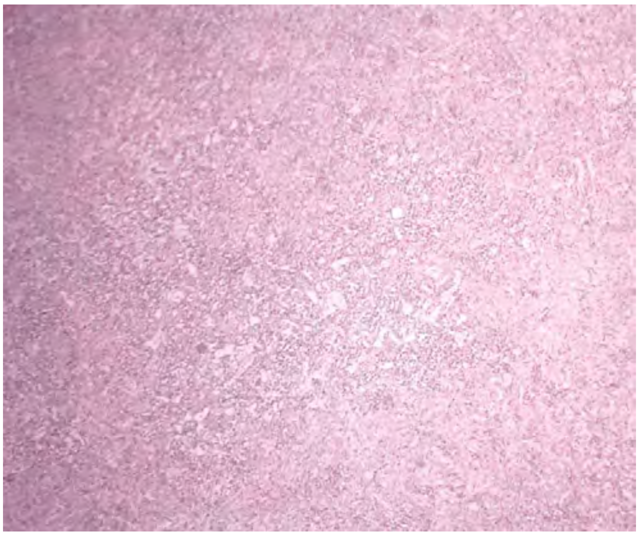

Figure 8. Sample 4 microstructure

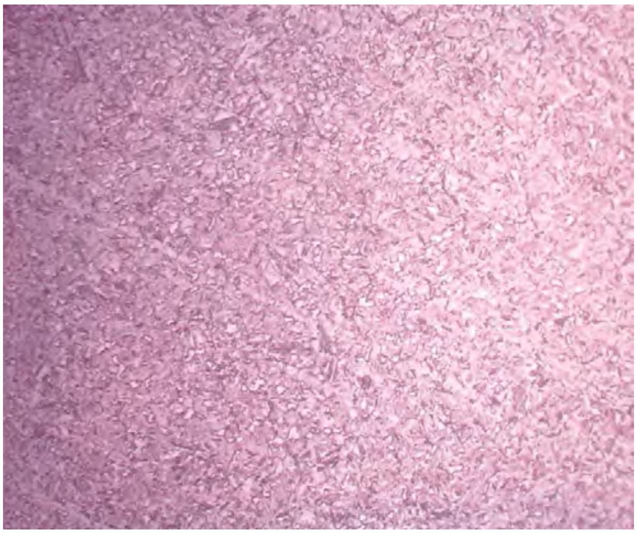

Figure 9. Sample 5 microstructure

5. CONCLUSIONS

During the project were analyzed possible causes of problems in heat treatment of steel alloy type P20 through practical analysis, including work methods and metallographic analysis.

In metallographic analysis was possible to observe the different microstructures of the samples by varying the conditions of heating and cooling. These changes were necessary for a detailed analysis of the components that constitute their structures.

A detailed study was carried out in order to identify how each component influences the structure, detecting possible causes for stress concentration generating possible surface cracks that undermine the process. Through this analysis it was possible to identify the component called retained austenite located in sample number 5 as heat treated and cooled according Tab. 2. Askeland and Phulé (2011) shows this component arises during the formation of martensite from austenite. As the needles or plates of martensite formed during cooling, they surround and isolate small areas of austenite. Thus, the remaining austenite deforms to accommodate the martensite which has a lower density.

However, for other areas with austenite be transformed, the surrounding martensite, which is mechanically resistant to deformation, must deform. Given this, the rest of austenite is transformed into retained austenite generating a stress concentration leading the formation of surface cracks that will only be identified after the whole process of treatment and posterior machining.

Thus, it is concluded that the use of inappropriate cooling mean can be the cause of the appearance of cracks and it is recommended to use a milder cooling mean such as oil for this purpose.

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