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Study of Microstructural Evolution and Mechanical Properties of SAE 1045 Commercial Steel Subjected to Tempering Heat Treatment in Different Cooling Means

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Abstract: The present study had as objective to study and evaluate the evolution of the microstructure and the mechanical properties of the SAE 1045 commercial steel, subjected to a tempering heat treatment at 850 ° C, using 3 different cooling media: air, water and mineral oil, with subsequent treatment of tempering at 300 ° C. Using hardness and optical microscopy as tools of analysis and data collection, it was possible to determine the evolution of the microstructure and the mechanical properties of the samples before and after the treatments, as well as to perform a systematic and comparative analysis between them. By means of the results obtained it can be concluded that the SAE 1045 steel does not present any alteration of its properties and microstructure when subjected to tempering using air as a cooling medium. However, in relation to the tempering using water and oil as cooling media, a severe microstructural alteration was observed, evolving completely to a microstructure formed by martensitic grains. A significant increase in the hardness of the material was also observed reaching a plateau of 400% hardness from the starting material soon after quenching and 340% after tempering.

Keywords: Quenching, tempering, SAE 1045 steel, cooling, hardness, microstructure.

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I. INTRODUCTION

Pure metals usually do not have the ideal characteristics to be applied in the manufacture of products used in society, in this context have arisen, metal alloys, which are mixtures of two or more metals or a metal with another simple substance during the melting. Steels are ferrous metal alloys which have the main constituent iron and possess a high range of mechanical properties, but are extremely sensitive to the carbon content, which is usually less than 1.0% by weight and is thus classified as medium-carbon steel. (CALISTER and RETHWISCH, 2016).

According to NBR 87/2000, which governs the numerical classification of carbon steels bound for mechanical construction according to its composition, SAE 1045 Steel is considered to be one of the most used. They are usually applied after heat treatments to improve their performance and are commonly used in the manufacture of general purpose components, where the mechanical strength required is higher than low carbon steels strength's. This material is mainly applied on shafts, pins, screws, clamps, among others. It is in this context that the present study has its relevance, since SAE 1045 steel is frequently used in several industrial sectors in its temperate and temperate condition, there is thus the need to understand and control its mechanical and microstructural behavior in face of these treatments and their variations, in order to understand the mechanisms responsible for the microstructural evolution and its properties, with the objective to know the main parameters and classify them.

II. MATERIAL AND METHODS

The characteristics of the starting material, test specimens and tempering and tempering treatment processes adopted by the research will be presented in the following topics.

Materials

The material used was SAE 1045 steel supplied by the company GGD Metais - Gonçalves Dias S / A Group in the form of bars 38mm in diameter, 5820mm in length and in the condition without heat treatment. The material supplied has a hardness of 15.0 ± 1.0 HRC and has a resistance limit of 690-700 Mpa, flow limit of

390-395 Mpa and a maximum elongation of 20% as well as a microstructure formed of 55% of pearlite and 45% of ferrite grains. Its chemical composition is presented in Table 1.

Table 1: Chemical composition of GGD 1045 steel

C	**Mn**	**Si**	**Cr**	**P**	**S**
0,43	0,65	0,22	0,36	0,012	0024

Source: Quality Certificate # 399829 - GGD Metals (2017)

The bars provided were cut and cold machined for the manufacture of test pieceswith dimensions of 10mm in diameter and 5mm in thickness (Figure 1).

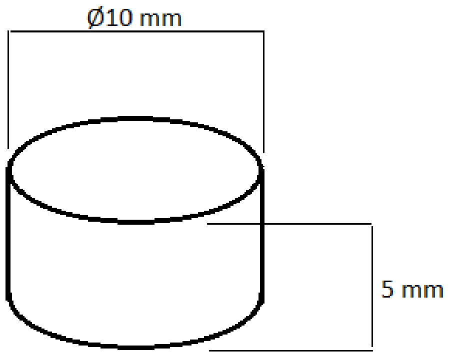


Figure 1: SAE 1045 steel test tube used in the analyzes.
Source: Author

Methods

Tempering treatment can be defined, such as heating the steel to its austenitizing temperature. The objectiveofthistreatmentistoobtainmartensite, whichrequires a fast cooling rate. The tempering process consists of the annealing of the annealed steel for agivenperiod, obtaining a microstructurecalledannealedmartensite, whichhasbetterductilityandlessinternalstressescomparedtomartensiteobtainedonly in thetemperingprocess (MACHADO, 2002).

The tempering treatments of the CPs were carried out at 850 ° C for 1 hour, for the purposes of this study 3 different cooling media were used: Air, water and mineral oil. The annealing was performed shortly after quenching when the temperature of the samples reached about 70°C, for which a temperature of 300°C wasusedwith a treatment time of2 hours.

III. RESULTS AND DISCUSSION

After each step of the heat treatment, the samples were selected and separated to be submitted to inlay and metallographic preparation in order to perform the microstructural analysis and the hardness tests in order to quantify and qualify the evolution of the mechanical properties and the microstructure. The tests and analyzes were carried out systematically in order to allow realistic comparisons between the data and also the literature.

In the hardness tests performed on the starting material, and on the material subjected to quenching treatments with cooling to air, water and mineral oil and after tempering (Table 2), it was observed that the material did not undergo any change in its hardness when subjected to quenching treatment with air cooling and not even after tempering, maintaining the same hardness of the starting material. On the other hand, there is a marked increase in hardness values in the other cooling mediums, reaching a plateau of 400% increase in hardness immediately after the quench treatment and 340% after quenching for cooling to water. On cooling with mineral oil, a slightly less hardness increase was observed, when compared to water cooling, of approximately 317% after tempering and 290% after tempering. The results are consistent with the research by DA SILVA (2012), who studied the heat treatment of tempering in SAE 1040 steel in different cooling media. According to Boyer and Cary (1988), the cooling rate of a sample varies according to the percentage of heat exchange generated by the cooling medium, also varying due to its size and geometry when both are in contact.

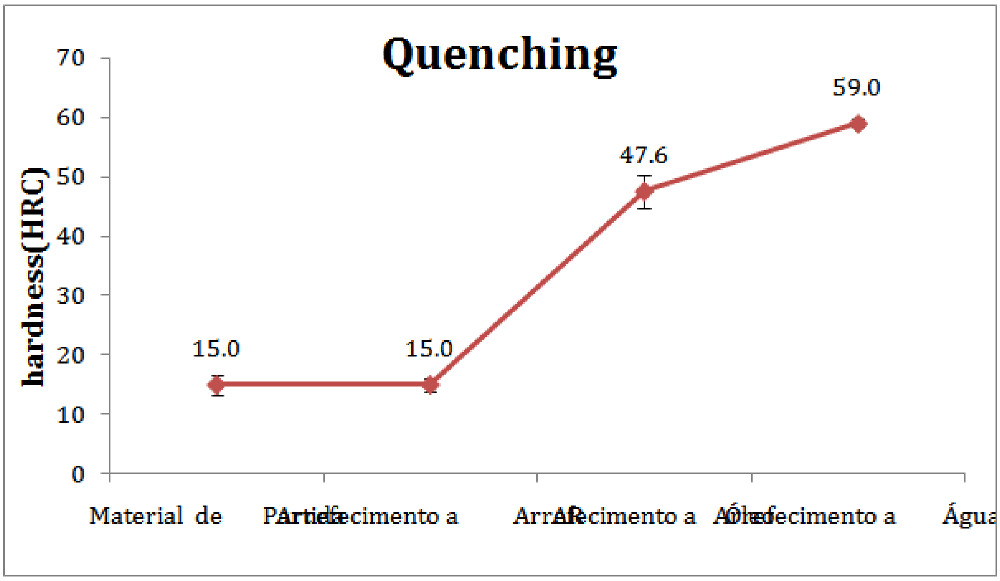
Of the cooling media used, water is the one that produces the most severe tempering, followed by oil and air, which corroborates with the results found in the hardness tests, Chart (s) 1 and 2 show the evolution of the values found in the hardness tests performed in the CPs at all stages of the thermal treatments.

Table 2: Results of the hardness test

SAE 1045 Steel							
Treatment	**Measures(HRC)**					**Average(HRC)**	**Standard deviation**
Starting material							
Untreated	13	15	16	17	14	15	1,0
Cooling - Ambientair							
Quenching	14	14	16	16	15	15	1,0
Quenching+ tempered	11	9	10	12	11	10,6	1,1
Cooling - Oil							
Quenching	51	45	50	47	45	47,6	2,8
Quenching + tempered	47	43	42	44	42	43,6	2,1
Cooling - Water							
Quenching	59	58	60	59	59	59	0,7
Quenching + tempered	52	50	47	52	55	51,2	2,9

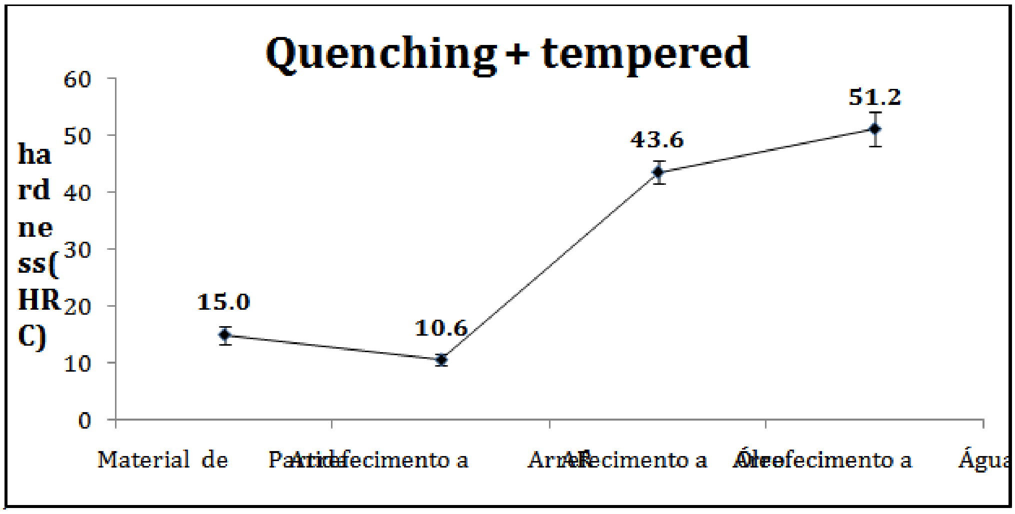
Source: author

Graph 1: Hardness test results after quenching treatment (860 ° C) with different cooling media.



Source: author

Graph 2: Results of the hardness test after tempering (850 ° C) and tempering (300 ° C) with different cooling media



Source: author

After the hardness tests the CPs were submitted to metallographic preparation and chemical attack with 3% nital, in order to analyze the evolution of the microstructure using optical microscopy. The resultsofthemicrostructural analysis were consistent with the results obtained in the hardness tests, since no change was observed in the micro-cracking of the air-cooled CPs, maintaining a microstructure formed of 55% of perlite and 45% of ferrite (Figure 2), the same as the starting material (Figure 3). It is noted that when heating the SAE 1045 Steel to its austenitizationtemperature (850 ° C) and then cooling it in non-flowing air, the low carbon content and the low cooling rate caused the microstructure not to altered to the point of tempering the material. Therefore, it does not alter its mechanical properties and its microstructure. CHIAVERINI in hiswork" Aços e Ferros Fundidos" of 2012, explains that the structure acquired in a material is directly linked to the speed with which it is cooled if the steel is cooled slowly as what happens when cooled by air without then it is not possible to obtain a martensitic structure, so it is not considered "tempered", since there is no collision between the internal structures and the material with a low carbon content does not allow its solid form, thus obtaining a microstructure which are the alternating layers of ferrite and cementite.

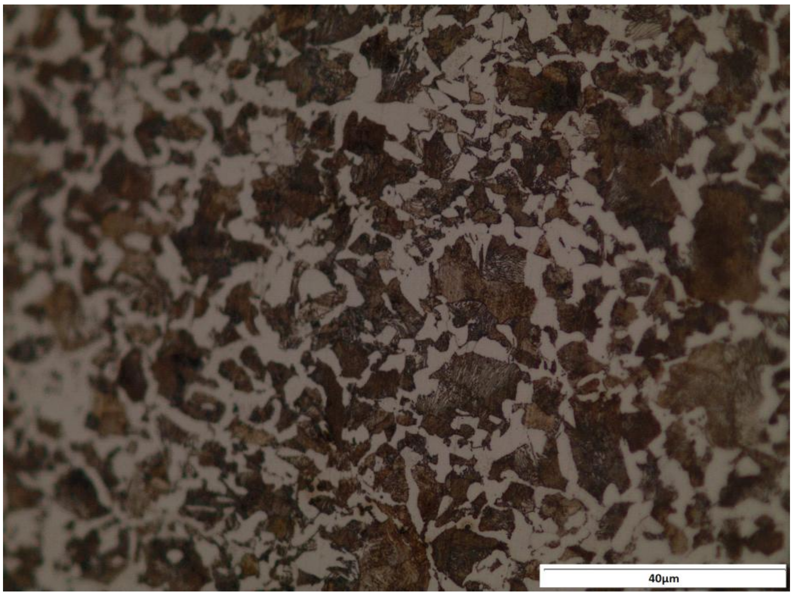


Figure 2: Perlite-ferrite microstructure of the SAE 1045 steel, after the heat treatment of quenching with air cooling and tempering (200X).Source: author

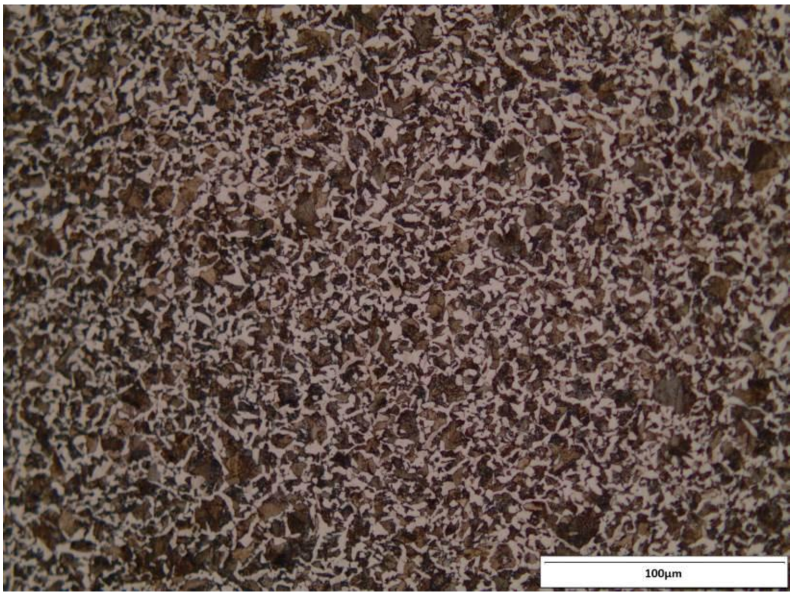


Figure 3: Perlite-ferrite microstructure of SAE 1045 steel, starting material without heat treatment (100x).Source: author

In contrast, when we performed the microstructural analysis of the samples after the treatments using as water and oil cooling media, a complete change was observed when compared to the starting material, and the new microstructure was formed by martensite grains (Figure 4, 5, 6 and 7). This observation is totally consistent with the results obtained in the hardness tests, since during the tempering treatment in the martensitic period the Carbon Steel is in its hardest phase, because when the martensite is formed.All the carbon found therein becomes solid due to the modification of its internal structure. The centered-face cubic CFC (austenite) does not adjust to the cubic-centered cubic CCC (ferrite) during quenching, since the high cooling rate and the amount of carbon in its interstices makes this event impossible, the needle-like microstructure is formed which are the solid carbons present. (DEDAVID, 2012).

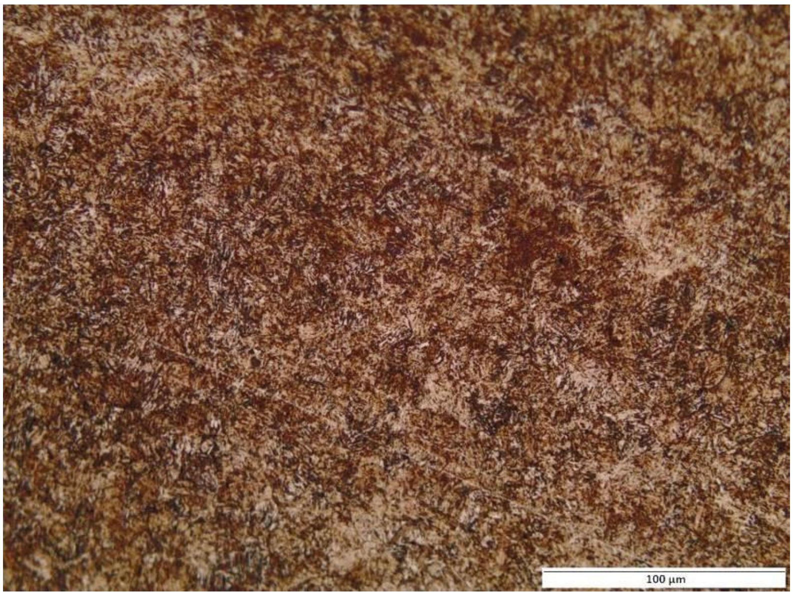


Figure 4: Martensitic microstructure of steel SAE 1045, after the heat treatment of quenching with oil cooling (100x).
Source: author

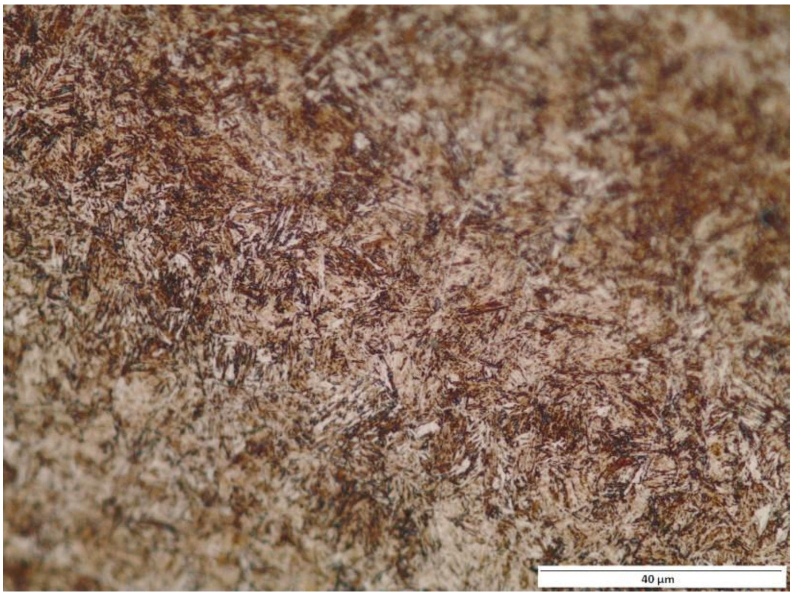


Figure 5: Martensitic microstructure of steel SAE 1045, after tempering heat treatment with oil cooling and tempering (500x).
Source: author

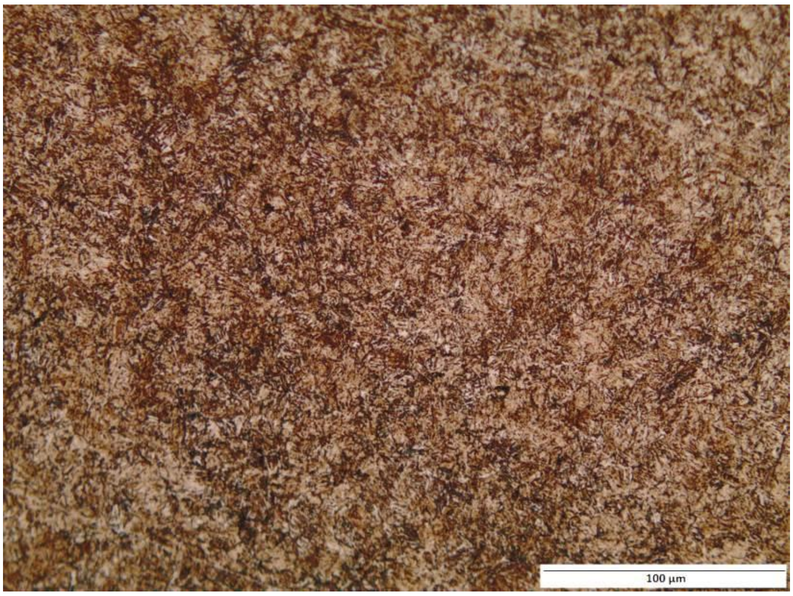


Figure 6: Martensitic microstructure of steel SAE 1045, after the quenching heat treatment with water cooling (100x).
Source: author

Figure 7: Martensitic microstructure of steel SAE 1045, after tempering heat treatment with water cooling and tempering (500x).
Source: author

Water at room temperature is a faster cooling medium because of its high latent heat and low viscosity when compared to air and oil, so the cooling medium is most effective for increasing the hardness of the material in the treatment. Ontheotherhand, it is important to point out that water has a remarkable oxidizing potential, which makes the material susceptible to cracks, since its cooling is very fast in the areas where the austenitic structure becomes martensitic. According to BOYER and CARY (1988), mineral oil is usually used to compensate for the disadvantages found in the water cooling medium, such as lower oxidation power, higher viscosity, consequently lower cooling rate, thus ensuring less distortion and less cracking.

When we observe the hardness after tempering, a slight reduction of the hardness values is observed, this is due to the relaxation of the internal tensions caused by the tempering treatment. The tempering is the reheating (at temperatures below the critical zone) of the steel already tempered, for acertainperiod, obtaining a microstructurecalledannealedmartensite, which has better ductility and less internal stresses when compared to the marten site obtained only in the tempering process (SCHEIDEMANTEL, 2014).

IV. CONCLUSION

It is concluded that SAE 1045 steel because of its low carbon content does not undergo any hardening effects or microstructural changes aimed at the formation of martensite when subjected to quenching treatment with air cooling. Thisfactislinked to the low latent heat of the medium which provides a low cooling rate, thus allowing sufficient time for the microstructure of the material to return to its original Perlite-Ferrite form, while retaining the same mechanical properties.

The quenchingtreatmentswithwater and oil cooling were efficient for the hardening of the material, as well as for its complete microstructural evolution. Of these two media, water was the most efficient in relation to the hardening, due to its high latent heat and its low viscosity when compared to the oil, which provides for this medium a higher cooling rate and therefore a higher hardness (FREITAS , 2016).

After tempering the results were in agreement with the expected one, in which a slight reduction of the hardness values was observed, a factor that is due to the relaxation of internal tensions caused by the tempering treatment.

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