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EFFECTS OF CARBURIZING AND CARBONITRIDING THROUGH CHEMICAL, MICROGRAPHIC AND HARDNESS ANALYSIS ON JIS SCM 420 STEEL

Bruno Mello de Freitas
Amazonas State University – UEA - Manaus - AM - Brazil
bfreitas@uea.edu.br

Genilson Colares Da Silva
Amazonas State University – UEA - Manaus - AM - Brazil
gcds.mec@uea.edu.br

Joaquim Souza de Oliveira
Amazonas State University – UEA - Manaus - AM - Brazil
jso.emt18@uea.edu.br

Jose Costa de Macedo Neto
Amazonas State University – UEA - Manaus - AM – Brazil
jmacedo@uea.edu.br

Adalberto Gomes de Miranda
Amazonas State University – UEA - Manaus - AM - Brazil
agmiranda@uea.edu.br

Abstract. *The thermochemical treatments of Carburizing and Carbonitriding through the diffusion of carbon and nitrogen on the surface of steels increase the hardness and the wear resistance of the material. However, they are required to assess the efficiency of such treatments. This work analyzed the effects of LPG gas carburizing and LPG ammonia nitride treatments on SCM 420 steel, which is a steel, used to manufacture equipment and motorcycle gear, followed by water quenching and air tempering. The comparison was made by Optical Emission Spectrometry, HMV hardness measurement and optical microscopy. The results showed that the percentage of carbon increased significantly in the carburized and carnonitrided samples, with 378.4% and 330.7%, respectively. The hardness was added in both treatments, but more on the surface of the carburized steel and the micrographs revealed the solubility of Carbon in Austenite, in addition to the formation of the tempered martensite microstructure. Therefore, the processes were efficient in changing the surface of the material, but leaving the core of the piece tenacious.*

Keywords: *SCM 420 steel, Thermochemical treatments, Microscopy, Toughness, Chemical analysis.*

1. INTRODUCTION

In search of new technologies, it is essential to acquire innovative materials or seek them to obtain the improvement to meet the requirements that this material will be delivered, especially metals that are of great importance in the engineering of manufacturing parts such as industrial, automotive, and domestic machinery where exceptional properties will always be required (Barra, 2013).

One of the most important materials for engineering are metals, which comprise the category characterized by the properties of ductility, malleability, gloss, hardness, tenacity and good electrical and thermal conductivity (Groover, 2014; Kong *et al.* 2013). Iron-carbon alloy parts and those of mechanical construction, depending on the application, it is necessary to submit them to thermal and thermochemical treatments in order to improve their properties (Chiaverini, 1986). The steel in this work is JIS SCM420 which consists of a steel alloy with medium hardness, temperature brittle, good weldability, less tendency to cold cracking and good machinability. It is generally used for parts that need high wear resistance, such as gears, shafts, high pressure tubes, all types of fastenings and other applications (Jeong, *et al.*, 2021b; JFS Steel, 2020; Masuyama, *et al.*, 2004). However, the surface may be subject to wear or damage during prolonged use. Therefore, SCM420 is often surface treated by carburizing before use (Jeong, *et al.*, 2021b), in addition to carbonitriding, followed by quench and tempering, which were performed in this work.

In thermochemical processes, hardness and wear resistance are increased through the addition and diffusion of carbon, nitrogen or boron on the steel surface. In other words, unlike thermal treatment, in thermochemical there is a partial change in the chemical composition of the material. We can mention as examples of these processes: carburizing, nitriding, cyanidation, carbonitriding and boration (Silva and Mei, 1988).

Gas carburizing, the process dealt with in this work, consists of submitting the material to a furnace containing carburizing gas and a carrier gas. The main vehicle gases used are composed of N_2, CO, CO_2, H_2, CH_2. The most used carburizing are hydrocarbons such as propane and natural gas (Boyer, 1987).

The carburized layer of a steel is formed through the process of carburizing which, according to Grosch (1993), it basically consists of two stages: carbon diffusion on the surface and hardening on the part. Diffusion results in a carbon concentration gradient in the carburized layer, from about 1.0% on the surface to the original carbon content of the steel, usually 0.2%. After quenching results in a hardness gradient and a compressive residual stress profile in the case hardening.

Some research involving carburized JIS SCM420 steel can be found in the literature. Jeon *et al.* (2021a) performed Fe-8Cr-3V-2Mo-2W powder deposition through the Directed Energy Deposition (DED) process in order to improve wear and fatigue resistance. It was observed that in the deposited layer of Fe-8Cr-3V-2Mo-2W there was an increase in the fraction of the martensite phase and the amount of precipitated carbides. As a result, the hardness increased from 48 to 62 HRc after heat treatment and the wear resistance was also significantly improved. Huang *et al*. (2011) investigate the effect of non-metallic inclusions on steel microstructures, inclusion morphology, matrix microstructure and fault fracture surface. The aforementioned authors noted that the inclusions in the material consisted mainly of dot-shaped oxide and silicate mixture, granulated oxide and silicate strip. Furthermore, the decarburized layer observed around the inclusions contained a microstructure composed of monophasic ferrite of the eutectic type due to the reaction between the inclusions and the matrix. With this, the authors concluded that the non-metallic inclusions and the decarburized layer would be the micro-cracks channel.

Industries are increasingly looking to improve their processes in order to improve the quality of their products, where there is a relentless search for the efficiency of these processes which the mechanical industry requires improvement in parts for different physical and mechanical properties. And the thermochemical treatment processes of gaseous carburizing and carbonitriding contribute precisely to this improvement, making the parts suitable to properly support the most different service conditions to which they are subject. However, proper techniques are needed to assess the efficiency of the treatment in order to analyze the effects that the treatments provided to the material.

Thus, chemical analysis techniques by optical emission spectrometry, microhardness with evaluation of the effective layer and micrography were used, in order to evaluate the carbon beneficiation on the surface of JIS SCM420 steel in the thermochemical treatments of Gas Carburizing and Carbonitretion, followed by Quenching and Tempering.

2. MATERIALS AND METHODS

2.1 Steel JIS SCM420

The steel JIS SCM420 comes from gears used in equipment responsible for manufacturing motorcycle parts in a company in the Industrial Pole of Manaus (PIM). The steel, which the study was conducted, is supplied according to the manufacturer in the normalized state and its chemical composition was performed by spectrometry, according to JIS G 4053 standard as shown in Table 1. For the study, the gear material was selected, which was divided into three samples with a diameter of 20 mm and a height of 10 mm, one sample for the comparative analysis, one for the thermochemical treatment of Carbonitriding and one for the treatment of Gas Carburizing. Both treatments were followed by quenching and tempering.

After the thermochemical treatments, comparisons were made between the samples, the chemical composition, hardness, effective layer of treatments and microstructures found. An evaluation was also carried out by the sanding method between the samples.

2.2 Gas Carburizing Treatment

The Gas Carburizing was submitted in a Dowa Thermotech Co. Ltd. oven, model S-TFC-100, which uses LPG as the carburizing gas. The sample was preheated at a temperature of 890 ± 5ºC, for 40 ± 10 minutes (min), with a percentage of Carbon (C) of 0.6 ± 0.1%, LPG of 0~4 L/min. and air at 0 L/min. The carburizing zone was carried out at a temperature of 900 ± 5ºC, time of 135 ± 10 min., % of C of 1 ± 0.1, LPG of 0~4 L/min. and air at 3 L/min. Before the quenching process a step zone was carried out at 850 ± 5°C for 45 ± 10 min., % C of 0.8 ± 0.1, GLP of 0~3 L/min. and air at 1 L/min. Quenching was at a temperature of 120 ± 5ºC by oil drop at a stirring of 100 rpm, for 15 min. Finally, tempering was performed at 180 ± 10ºC in 120 ± 20 min. and cooled in ambient air.

2.3 Carbonitridation Treatment

The carbonitriding treatment was carried out in a Dowa Thermotech Co. Ltd. oven, model S-TFC-100, using LPG gas for carburizing and ammonia for nitriding. The sample was preheated at a temperature of 910 ± 5ºC, for 65 ± 10 min., with the addition of Carbon (C) at 0.6 ± 0.1%, LPG between 0 and 4 L/min. and air at 1 L/min. Carburizing was at a temperature of 920 ± 5ºC, for 195 ± 10 min., % C of 0.9 ± 0.1, GLP of 0 to 4 L/min. and air at 3 L/min. Carbonitriding was performed at 840 ± 5°C for 65 ± 10 min., % C of 0.8 ± 0.1, GLP of 0 to 3 L/min., Ammonia of 3 ± 0.5 L/min and air at 1 L/min. Quenching was carried out at 120 ± 5ºC by oil drop and stirring at 250 rpm, for 15 min. Finally, tempering was performed at 180 ± 10ºC in 120 ± 20 min. and cooled in ambient air.

2.4 Chemical analysis

For chemical analysis, using the spectrometry method, equipment from the Shimadzu brand was used, in accordance with JIS G 4053. Also, the average of three readings in each sample was considered.

2.5 Microhardness

The evaluation of microhardness on the surface of the three samples, by the Rockwell A method, was carried out in MITUTOYO brand equipment. The conversion to the HmV, HRC and HRB scales was performed according to the ASTM A370 standard. Five HmV hardness measurements located at 0.05 mm on the surface of the normalized, carburized, and carbonitrided sample were averaged. For the analysis of the effective layer of thermochemical treatments, the JIS G 0559 method and the specified value were used to determine the effective layer (50 HRC = 513 HmV) of the SAE J 423 standard. According to Korean Industrial Standard KS D ISO 4507, the effective carburizing layer is commonly defined as the point on the hardness curve corresponding to 550 HV in the Vickers hardness test.

2.6 Metallography

The metallography was carried out according to the ABNT NBR 15454 standard. Sanding was carried out, followed by polishing with a diamond paste at a particle size of 1μm and chemical attack with 5% Nital. During sanding, the C content was evaluated by the sanding method. Subsequently, optical microscopy analysis was performed using Olympus brand equipment in order to identify the existing microstructures in all samples, in addition to observing the thickness of the effective hardened layer in the carburized and carbonitrided samples.

3. RESULTS AND DISCUSSIONS

Table 1 shows the percentage average of the chemical analysis of the normalized steel and after its thermochemical treatments performed.

It is evidenced that the normalized sample is in accordance with what is specified for the material. After carburizing, the C content in the carburized sample increased to 0.825% C (gain of 0.607% C) and in the carbonitrided sample this increase was a little smaller, with 0.721% C (gain of 0.513% C), indicating that it really was insertion of this element in the sample was performed in both thermochemical treatments.

Table 1. Chemical composition by spectrometry method, according to JIS G 4053. Values in %.

SCM420	**C**	**Si**	**Mn**	**P**	**S**	**Ni**	**Cr**	**Mo**
Specified	0.18 ~ 0.23	0.15 ~ 0.35	0.60 ~ 0.90	0.030 máx.	0.030 máx.	0.25 máx.	0.90 ~ 1.20	0.15 ~ 0.25
Normalized	0.218	0.270	0.707	0.011	0.021	0.081	0.944	0.201
Carburized	0.825	0.264	0.668	0.013	0.011	0.082	0.866	0.205
Carbonitrided	0.721	0.280	0.769	0.012	0.150	0.082	0.998	0.206

Figure 1 demonstrates the carbon processing on the surface of samples submitted to thermochemical treatments. It is observed that the carburized sample had higher carbon content compared to carbonitrided.

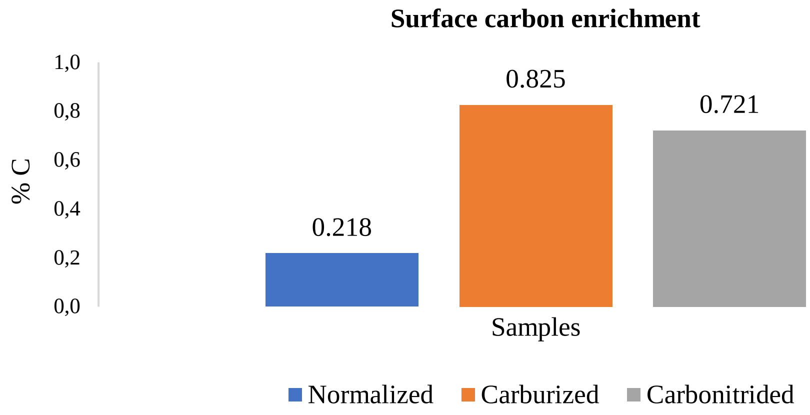
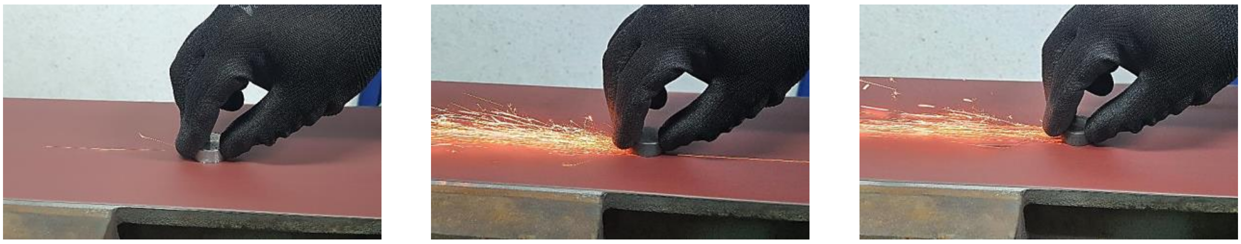


Figure 1. Benefits of carbon on the surface of samples submitted to thermochemical treatments.

Figure 2 shows the evaluation of the carbon content in the samples by the sanding method. Based on the volume of sparks, it is observed that the carburized part had a higher carbon content on the surface, confirming the result obtained by spectrometry.



(a) (b) ©

Figure 2. Evaluation of the carbon content in the samples by the sanding method, (a) normalized sample, (b) carburized and (c) carbonitrided.

The analysis of the hardness on the surface of the samples, by the Rockwell A method, being performed the conversion to other scales using the tables of the ASTM A370 standard, is described in Table 2. The average hardness on the surface of the carburized sample was 697 HmV, where it also results in increased wear resistance of the material surface. The carbonitrided sample had a slightly lower mean hardness compared to the carburized sample, with 653 HmV, but higher than the normalized sample, which obtained 453 HmV.

This increase demonstrates that there was thermal treatment and is primarily due to the addition of carbon in the case of carburizing and the addition of carbon and nitrogen in Carbonitriding. Another reason for the hardness gain is that, according to Callister, 2012, as they are interstitial atoms, carbon and nitrogen, when added to the metal's crystalline structure, occupy the empty spaces, making it difficult for neighboring atoms to deform when a force is imposed on the metal material.

Table 2. Average hardness on the surface of the samples, being converted to other scales according to the ASTM A370 standard.

SURFACE HARDNESS	**HRA**	**HmV**	**HRC**	**HRB**
Normalized	57	200	-	93
Carburized	81	697	60	-
Carbonitrided	80	653	58	-

The evaluation of the effective heat treatment (quenching) layer by the hardness dispersion method is shown in Figure 3. This value is determined at the hardness of 50 HRC = 513 HmV, as per SAE J 423 standard. The effective layer was found with 0, 68 mm in the hardened sample, 0.55 mm in the carbonitrided sample and as the depth increases, the hardness gradually decreases with the carbon concentration gradient. The effective layer was greater in the carburized sample, in addition to the higher hardness value of 768.82 HmV, similar to the result of the work by Lee *et al.*, 2021, where a value of 774 (± 4.31) HV was found for the same SCM420 steel.

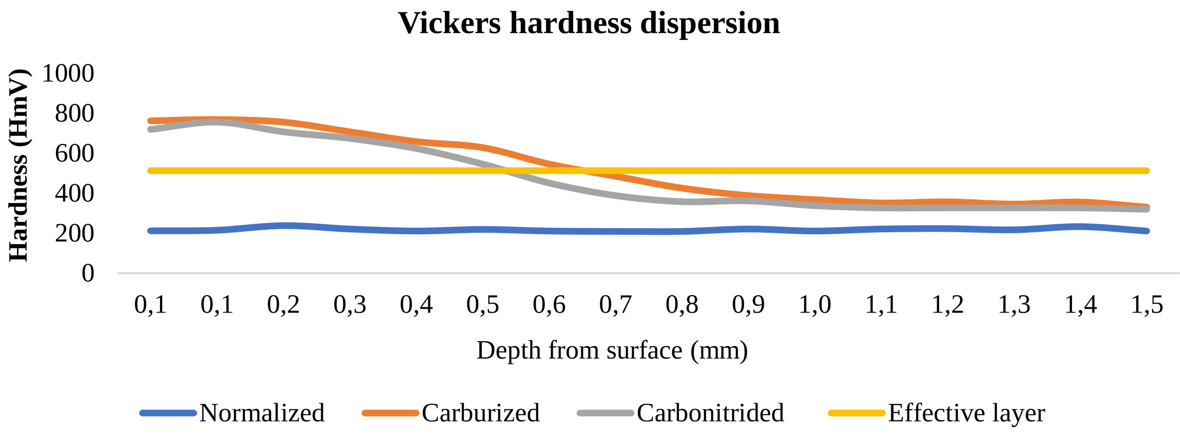
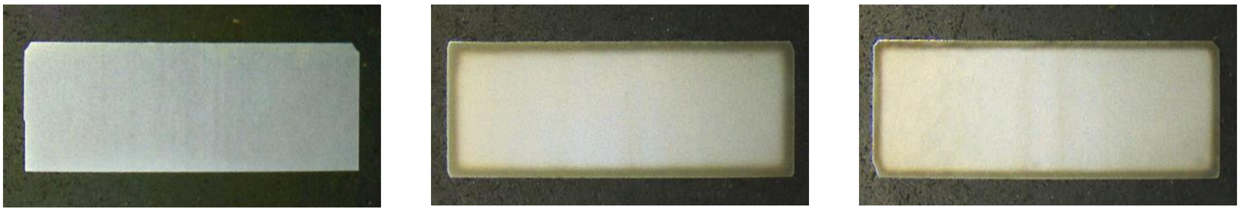


Figure 3. Effective heat treatment layer (quenching), by the method described in JIS G 0559.

Figure 4a is the sample in its normalized state before performing the heat treatments of the study. An excellent uniformity of the thickness of the hardened layer was observed in the carburized sample (Figure 4b) and in the carbonitrided sample (Figure 4c).



(a) (b) (c)

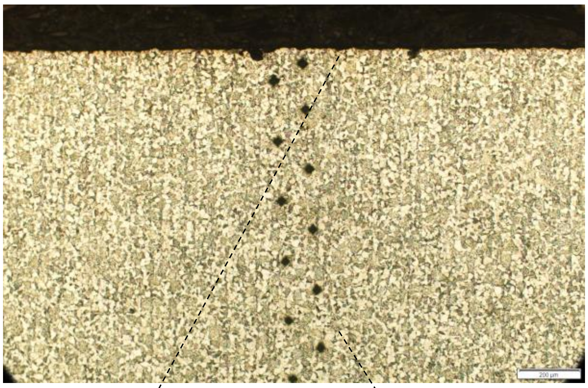
Figure 4. Sample (a) Normalized; Uniformity in the thickness of the quenched/tempered layer in the (b) carburized and (c) carbonitrided sample.

In Figure 5, the microstructures found in the samples are identified. Figure 5a (100x), 5b (500x) and 5c (1000x) shows the sample in its normalized state, that is, before the thermochemical treatments performed. Figure 1b corresponds to the surface and Figure 1c corresponds to the core of the sample, where the presence of the microstructure ferrite (lighter area) and pearlite (darker area) is evidenced.

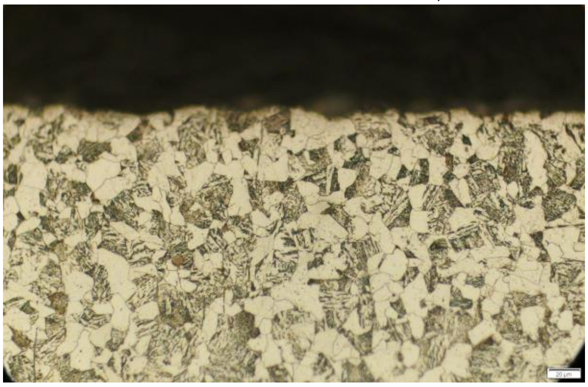
In Figure 5d (100x), 5e (1000x), 5f (1000x) and 5g (1000x) the sample is analyzed after the Carburizing/Quenching/Tempering treatment. In Figure 5e (surface) the martensitic microstructure (Sorbite) is shown with the presence of Austenite retained in the martensitic matrix, where the interstitial atoms, mainly carbon, remain in the Austenite crystal structure, which makes its deformation difficult. According to Parrish (1980) the retained austenite is formed when performing sudden cooling in steels, where martensite is formed together with the previously unstable austenite becomes stable at room temperature. Martensite increases hardness as there is no diffusion of carbon atoms in the steel structure due to the rapid cooling imposed. In Figure 5f (effective layer boundary) and Figure 5g (core) the martensitic matrix with retained Austenite is confirmed in both.

In Figure 5h (100x), 5i (1000x), 5j (1000x) and 5k (1000x) the sample is analyzed after the Carbonitriding/Quenching/Tempering treatment. Figure 5i (surface) shows the presence of the tempered Martensite microstructure (Sorbite), with the presence of Austenite retained in the martensitic matrix in an amount greater than the carburized sample. This larger amount of austenite resulted in the lowest microhardness, confirmed by Figure 3, where all the measured microhardness dispersion points are smaller in relation to the carburized sample. In Figure 5j (effective layer boundary) and Figure 5k (core) a martensitic matrix with retained Austenite is confirmed in both.

The scales in Figures 5a, 5d and 5h are 200 µm and the other figures are in the 20 µm scale.



(a)



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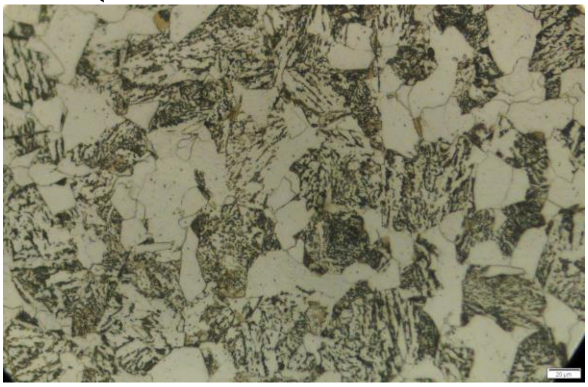
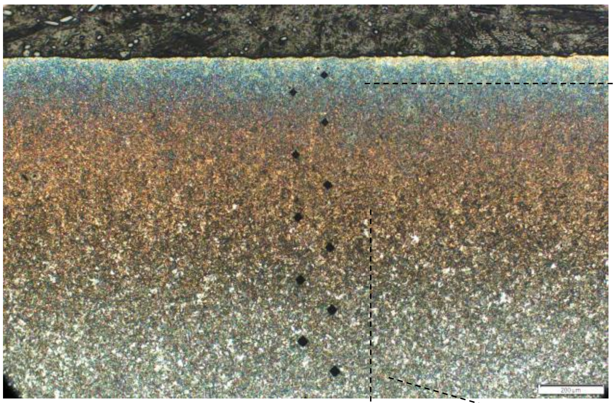
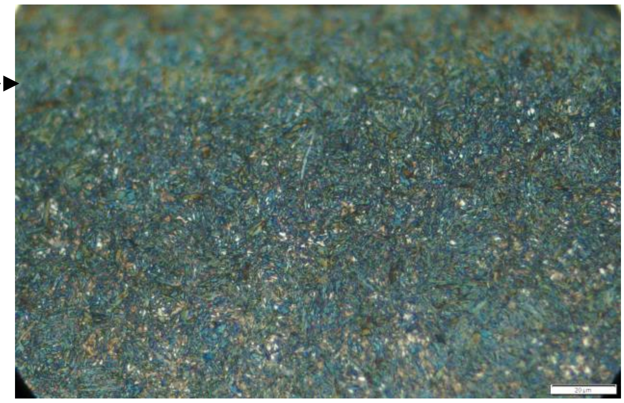


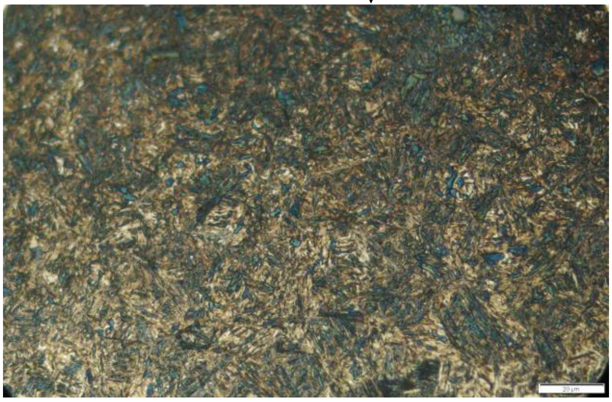
(c)



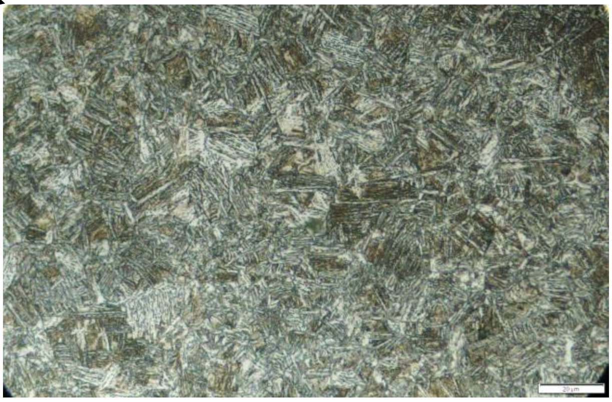
(d)



(e)



(f)



(g)

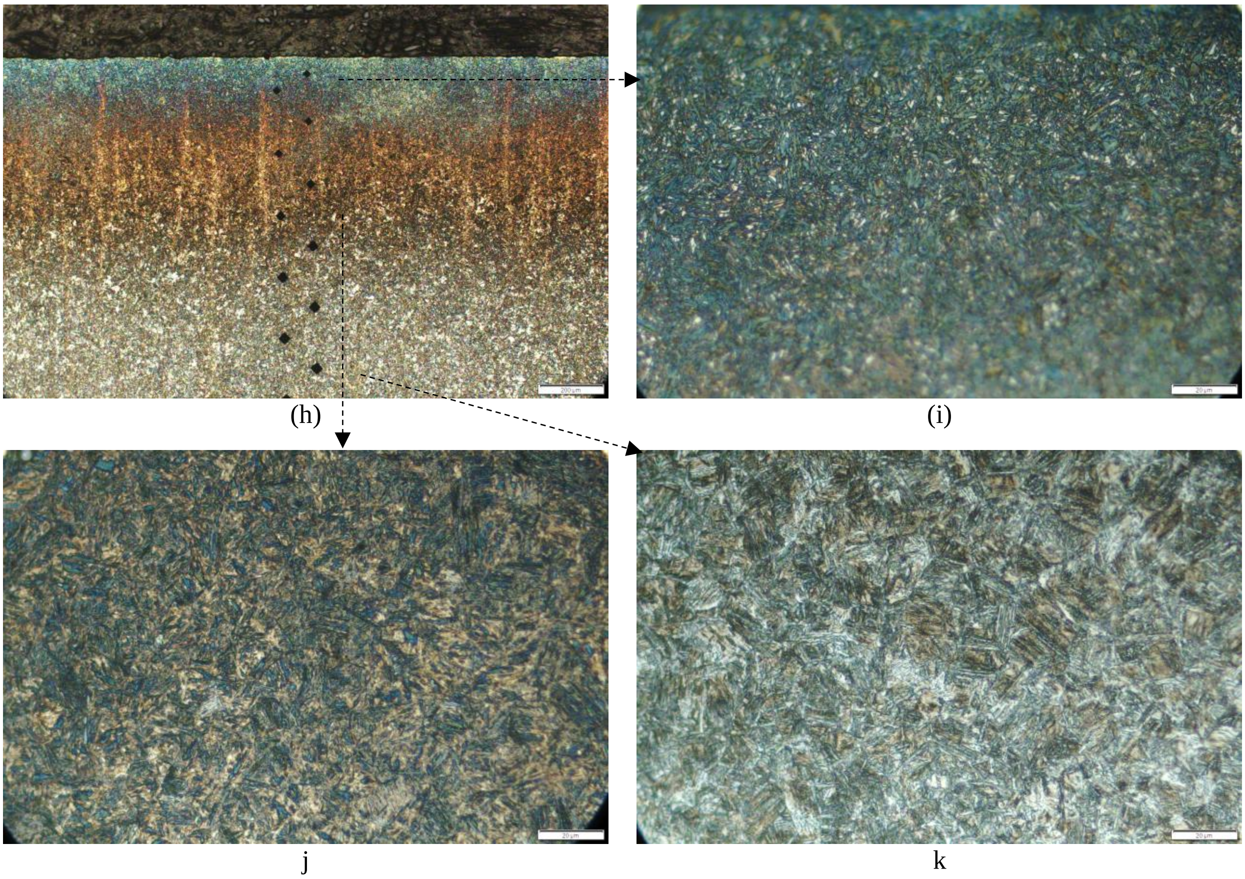


Figure 5. Microstructures of the normalized sample a) 100x, b) 500x, c) 1000x, carburized sample d) 100x, e) 1000x, f) 1000x, g) 1000x, carbonitrided sample h) 100x, i) 1000x, j) 1000x and k) 1000.

4. CONCLUSION

The material under study is actually a SCM420 steel, as the chemical percentages of the material analyzed by spectrometry are within the range established by the standard. Also, by spectrometry and after the thermochemical treatments performed, there was a gain in the carbide agent, consequently causing an increase in the hardness and wear of the material.

The effective layer of the heat-treated samples was homogeneous, but in the carburized sample this value was about 20% higher than the carbonitrided sample.

The micrographs revealed that before the treatments the microstructure that was basically formed by ferrite and pearlite and, after the thermochemical treatments, presented a microstructure consisting of tempered martensite (Sorbite) and retained Austenite. A factor that implies a greater microhardness in the carburized sample is the presence of austenite retained in the martensitic matrix in a smaller amount, where the microhardness in all its measurements is greater in relation to the carbonitrided sample.

Thus, the thermochemical treatments were efficient for the SCM420 steel and can be normally used in the manufacture of gears for motorcycles and bicycles.

5. ACKNOWLEDGEMENTS

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