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Characterization of 5052 Aluminum Alloy under Different Heat Treatments[1]

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Abstract

The use of aluminum alloys has grown considerably over the years, the fact occurs due to the inherent characteristics of the material, such as low density and corrosion resistance in the most varied environments. The present work proposes to characterize the microstructure of the aluminum alloy 5052, which is an aluminum and magnesium alloy that was subjected to different heat treatments. The proposal to study the league is justified by the use of it in sectors such as the naval and with that the analysis of its characteristics can bring possibilities of improvements to its properties, revealing positive and negative points, and improve the performance of the alloy during its applications. As a methodology to achieve the objective, four samples of 5052 aluminum were used, one was subjected to annealing, one to normalization, and two to solubilization (one cooled in water while the other in oil). Afterwards, the samples were embedded, sanded, polished and attacked with hydrochloric acid to visualize its microstructure in an optical microscope. As a result, four samples were obtained with different microstructures, the annealed sample showed a greater amount of a phase (rich in aluminum) and precipitated magnesium in the form of dark spots, the normalized sample presented

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[1] Caracterização da Liga de Alumínio 5052 Submetida a Diferentes Tratamentos Térmicos

the a phase and the β phase (in vermicular form), the solubilized samples showed a saturated magnesium microstructure (martensitic microstructure). In this way, it can be concluded that, just as in ferrous alloys, non-ferrous alloys can go under heat treatments and have changes in their microstructural characteristics. The application of heat treatments to the aluminum alloy 5052 caused considerable changes in the microstructure of the alloy and even the type of cooling used during the procedure influenced these changes.

Key words: Aluminum, Heat Treatment, Microstructure, Cooling.

Resumo

O emprego das ligas de alumínio tem crescido consideravelmente com o passar dos anos, fato que ocorre pelas características inerentes do material como a baixa densidade e a capacidade de resistência à corrosão nos mais variados ambientes. O presente trabalho propõe como objetivo caracterizar a microestrutura da liga de alumínio 5052, a qual é uma liga de alumínio e magnésio que foi submetida a diferentes tratamentos térmicos. A proposta de estudo da liga se justifica pelo emprego dela em setores como o naval e com isso a análise de suas características pode trazer possibilidades de melhorias às suas propriedades, revelando pontos positivos e negativos, e aprimorar o desempenho da mesma durante suas aplicações. O objetivo do trabalho foi caracterizar a microestrutura de uma liga de alumínio ligada ao magnésio, a qual foi sujeita a diferentes tipos de tratamentos térmicos analisando as fases existentes na liga após diferentes tratamentos térmicos e assim orientar a utilização das mesmas. Como metodologia para alcance do objetivo se utilizou quatro amostras do alumínio 5052, uma foi submetida ao recozimento, uma à normalização, e duas à solubilização (uma resfriada em água enquanto a outra em óleo). Na sequência, as amostras foram embutidas, lixadas, polidas e atacadas com ácido clorídrico para visualização de sua microestrutura em microscópio óptico. Como resultado obteve-se quatro amostras com microestruturas distintas, a amostra recozida apresentou maior quantidade de fase a (rica em alumínio) e precipitados de magnésio na forma de pontos escuros, a amostra normalizada apresentou a fase a e a fase β (em forma vermicular), as amostras solubilizadas apresentaram uma *microestrutura saturada de magnésio (de aparência similar à microestrutura martensítica). Desta forma pode-se chegar à conclusão de que assim como nas ligas ferrosas, as ligas não ferrosas podem ser submetidas a tratamentos térmicos e ter modificações de suas características microestruturais. A aplicação dos tratamentos térmicos na liga de alumínio 5052 causou mudanças consideráveis na microestrutura da liga e até mesmo o tipo de resfriamento empregado durante o procedimento influenciou em tais mudanças.*

Palavras-Chave Alumínio, Tratamento Térmico, Microestrutura, Resfriamento.

I INTRODUÇÃO

The scope of the application of metal alloys in the daily life of today's society is indisputable, but each has inherent characteristics and certain peculiarities in its behavior. To facilitate the study, metal alloys are divided into two distinct groups, depending on the chemical composition, being named ferrous alloys and non-ferrous alloys. The main differential between classes is the existence of iron in the composition, in ferrous alloys this is the main constituent while in the other there is no such highlight [1]. It can be said that ferrous alloys have a much broader field of application than other alloys because of certain desirable and inherent behaviors. However, ferrous alloys also have limitations such as high density and susceptibility to corrosion in common environments, which makes the application of non-ferrous alloys more desirable in certain cases [1].

A very important alloy among the group of non-ferrous alloys is aluminum alloy, which stands out for having a relatively low specific mass, high electrical and thermal conductivity, ability to resist corrosion in various types of environments, in addition to having high ductility which facilitates the work and application of these alloys in various sectors [1]. As aluminum is bonded to other elements it is possible to obtain materials with good resistance and in some cases this resistance may be equal to that of some steels, in addition to a beneficial increase in corrosion resistance. An important fact is that aluminum alloys have been used as an alternative to replace low-carbon steel, due to its lightness, in structural applications [2]. Furthermore, there is currently a growing trend in the consumption of aluminum and its alloys caused by the physical, chemical and mechanical aspects that the material presents [3]. This fact may be an advantage for Brazil, because it has the third largest reserve of bauxite [3], and the country finds itself as the eleventh producer of primary aluminum and third producer of bauxite [4].

The alloy that will be studied in this work is characterized as an aluminum-based alloy linked to magnesium, being its number of associations with aluminum 5052. The combination of the two elements is quite peculiar, as aluminum and magnesium are elements very close in the periodic table, which makes them form a solid substitutional solution, in which the magnesium atoms will replace some atoms of aluminum without there being a change in the crystalline structure of aluminum [5]. The result of the combination is an alloy with desirable properties, such as good mechanical properties and mechanical strength [5]. Regarding the use of the alloy, we can mention the use in fuel tanks, rivets, wires and aircraft fuel and oil lines [1]. In some cases, this alloy can be used in the naval sector to build propellers for boats. The chemical composition and microstructure from solidification or heat treatment has a close relationship in the properties of aluminum alloys [6], thus the study of its microstructure can facilitate the use of the alloy in its area of operation and make the best use of its characteristics for the most appropriate performance possible. The Aluminum 5052 alloy has magnesium as the main binding element (2.5% w) containing also Chromium (0.25% w) [1]. Table 1 shows some characteristics of this alloy.

Table 1: Mechanical Proprieties of 5052 Aluminum alloy. [1]

Mechanical Proprieties		
Tensile Stress [MPa (ksi)]	Limit of Elasticity [MPa (ksi)]	Elongation [%]
230(33)	195(28)	12-18

With the knowledge of the composition of the alloy in question it is possible to study the changes that the alloy may face according to the process employed. This study is possible with the aid of the aluminum-magnesium phase diagrams (Figure 1), since the amount of chromium in the alloy is very small. Through the diagram you can reach several conclusions, first the diagram is classified as a binary Al-Mg diagram, as it has temperature and composition as variables, and second there are intermediate solid solutions (γ, β and ε) and solid terminal solutions (α and δ), which have different characteristics in the study of microscopy. The α phase is rich in aluminum while the δ phase is rich in magnesium, through the diagram it is also possible to see the temperature at which the aluminum and magnesium pass to the liquid state, the first at 660,452 ºC and the second at 650ºC.

The diagram also contains points where important reactions take place, such as the eutectic point, where a liquid phase turns into two solid phases through cooling or the reverse situation through heating, which can be found twice, once in the composition of 35, 6% magnesium at a temperature of 450ºC (containing the solid α and β phases) and another in the composition equivalent to 66.7% of magnesium at a temperature of 437ºC (containing the solid γ and δ phases).

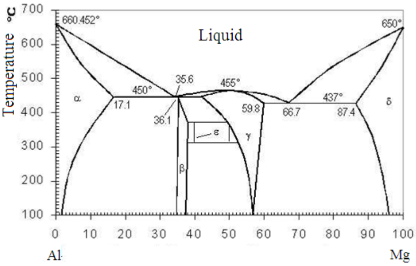

Figure 1: Al-Mg phase diagram [7]

With the used of diagram of figure 2 is possible to visualize better the location in the diagram of the 5052 aluminum alloy. This is at room temperature containing the α and β phases, but it can contain only the α phase depending on the temperature at which the material is submitted, and because it contains a low percentage of magnesium, it can be subjected to heat treatment of solubilization.

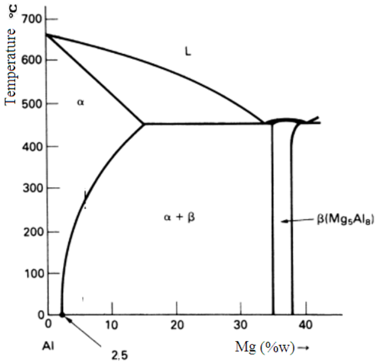

Figure 2: Location of the 5052 aluminum alloy in the diagram. [8]

One way to improve the properties of these alloys is the use of heat treatments, which consist of a set of heating and cooling techniques used to change the microstructure of the material and consequently its mechanical properties. The application of heat treatments in non-ferrous alloys is as important as the application in ferrous alloys [9], through this application it is possible to improve the properties of the alloys and expand their fields of application. Aluminum alloys can be divided into two large groups, when it comes to the application of heat treatments, the first group is that of non-heat-treatable alloys, which have low mechanical properties and are only improved by cold working, the second group composes the alloys that are heat treatable, properties such as hardness can be modified by means of heat treatments [9]. The heat treatments most commonly used in aluminum alloys are annealing and the solubilization technique. The main purpose of annealing (reheating) is to reduce hardness as well as internal stresses, the treatment is commonly used on parts that have been subjected to work at cold [9]. The process basically consists of raising the temperature of the aluminum to temperatures between 260 ºC to 440ºC for a determined time and cooling the piece slowly [9]. Cooling is traditionally carried out inside the oven. It is also possible to use standardization in the treatment of aluminum alloys, a process that is very similar to annealing, but cooling is carried out in air.

The thermal treatment with the solubilization technique proposes to raise the temperature of the material to a certain temperature where the alloy elements form a solid solution with the aluminum and from there the sample is subjected to a rapid cooling

[9], this will cause with the solute being retained in the solution forming different solid solutions because at high temperatures the alloying elements form a solid solution with aluminum and due to the fact that the cooling is fast, the components separate at room temperature, however the permissible percentage that can being dissolved at low temperatures is much lower which will cause the formation of a new solid solution. The objective of the work was to characterize the microstructure of an aluminum alloy linked to magnesium, which was subjected to different types of heat treatments by analyzing the existing phases in the alloy after different heat treatments and thus guiding their use.

MATERIALS AND METHODS

Firstly, a roadmap of what would be necessary to achieve the objectives set out in this study was established, so it was necessary to build an experimental plan. In planning it is possible to survey the materials and techniques that will be indispensable for carrying out laboratory procedures. Next in figure 3 is a flowchart to provide an overview of the study procedures.

The aluminum alloy 5052, used in the form of a bar without the application of previous heat treatments, was supplied by EDIFIK Company (Edições e Estruturas de Alumínio Ltda). This alloy is widely used in the naval sector and therefore the study of its characteristics can bring improvements to its properties. Because it is essential to perform the micrograph of the alloy, it was necessary to cut the aluminum bar into small samples, totaling four, with dimensions of 12mm x 12mm x 4mm thick. The cut was carried out using an automatic cutting machine and using water as a lubricating liquid. Heat treatment was carried out on all four samples, each with a different cooling. One sample was subjected to the annealing treatment, one to normalization, while the remaining two were subjected to the solubilization treatment. The oven used for the procedure was a oven type MUFLA, Brand: Jung 7728, Model LF09618, which was heated to 400 ° C and maintained for 20 minutes with the four samples inside. Then, three of the samples were removed, one of which was cooled in oil, the second in water, the third in air and the fourth sample that remained inside the oven and was cooled inside it. The table 2 show the different process.

Subsequently, microscopic analyzes were performed, which are of great importance to determine the characteristics of the materials, because through it is possible to observe the microstructure of the material under study, since the properties of the materials are directly linked to their microstructural characteristics. There are several techniques for obtaining the micrograph (image of the microstructure) of the material, among the most used can be mentioned the optical, electronic and scanning microscopy.

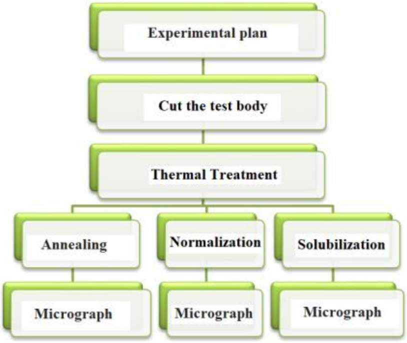

Figure 3: Flow chart of work steps

Table 2: Heat treatments applied to the 5052 alloy

Test body	**Thermal Treatment**	**Temperature (°C)**	**Time (min)**	**Cooling system**
01	Annealing	400	20	oven
02	Normalization	400	20	air
03	Solubilization	400	20	water
04	Solubilization	400	20	oil

In the present work, the optical microscopy technique was used, its main differential from the others for the use of an optical microscope to visualize the microstructure. Optical and lighting systems are essential for the technique, moreover it is necessary that the sample surface to be analyzed has been prepared [1]. The preparation of the sample requires that it has been sanded and polished properly until the surface has a mirrored aspect and this must be attacked by a chemical reagent that allows the development of the microstructure, from this moment the sample can be positioned in the optical microscope and the microstructure to be visualized [1]. The microstructure characteristic of the sample, such as the brightness and texture of each grain, depends on its reflectance property [1].

To be possible the micrography of the samples, each sample was embedded in black Bakelite, using an embedding machine Brand: SOLDTEST, Series: 6738, with a pressure of 150 kgf / mm². And then, the samples were pass through the sanding sequence (180, 400, 800, 1200, 1500), for a time of one to two minutes each to remove all the more abrupt imperfections (scratches, bakelite inclusions, etc.). In the sequence, the samples were pass through the polishing process to finish the surface, for this it was necessary to use a polishing cloth with a diameter of 200 mm and the use of diamond paste of 1µ (micron) for the necessary time that each requested so that they had a surface free of scratches and imperfections.

Chemical attack was carried out after polishing process, using a solution of hydrochloric acid as a reagent, which is widely used for the development of microstructures of aluminum alloys [11], the reagent was placed in each sample for 15 minutes. From this moment microscopic visualization is possible, an optical microscope model Olympus CX31 and MOTICAM 1000 camera was used. Each sample was visualized at 100x and 400x magnification. Figure 4 shows, in a more summarized form, all the steps that were necessary to complete the micrograph stage.

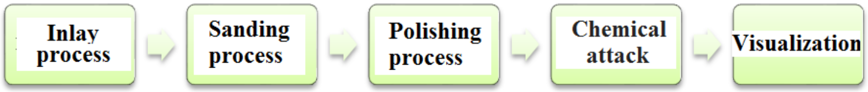

Figure 4: Laboratory procedures.

RESULTS AND DISCUSSION

As a main result, it was found that there were significant changes in the microstructure of each sample. Such microstructural transformations depended on the type of heat treatment to which each was subjected. With the help of the phase diagram (Figure 1 and Figure 2) it was possible to know the inherent characteristics of the alloy, as it is possible to know which phases are present in each stage of the process that the samples were submitted to.

Figure 5 shows the microstructure of the sample subjected to the annealing heat treatment (specimens1), which presented in large part the α-aluminum rich phase (light region) with magnesium precipitates (dark spots) comprising the β phase. It is also possible to notice the directional overlap of magnesium precipitates that are aligned horizontally. The directional overlap is linked to the rolling process that the metal has undergone, which causes the grains to be compressed and elongated. In this sample, it is possible to perceive the largest amount of α phase, which has softness as one of its main characteristics, which is justified by the fact that the main objective of annealing is to reduce the hardness and internal stresses in the material [9]

The normalized sample presented in its microstructure the α phase (rich in aluminum), which served as a kind of matrix in the background, as seen in the micrograph of Figure 6, and a much smaller amount of magnesium precipitates in the shape of dark spots. and the presence of thin streaks (vermicular format) that extend throughout the sample, which are characterized as β phase.

It is important to mention that the vermicular shape is found in the vermicular cast iron, however the striations are much thicker. The percentage of magnesium contained in vermicular iron is responsible for the appearance of this format in the microstructure [10], which justifies the appearance in the 5052 aluminum samples analyzed since the alloy contains magnesium as the main aluminum binder.

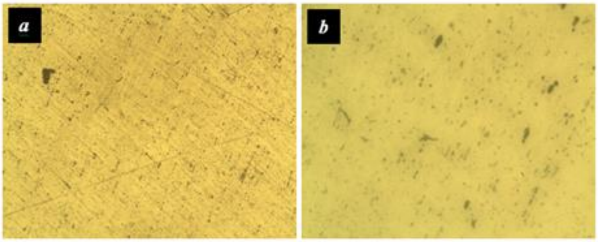

Figure 5: Annealed Sample (a) 100 X magnification and (b) 400 X magnification.

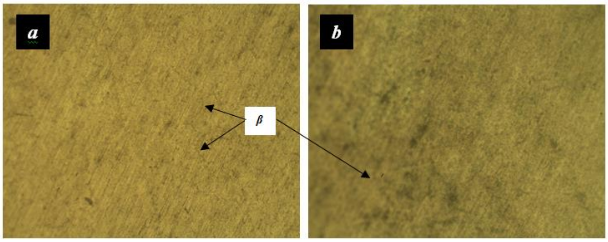

Figure 6: Normalized Sample (a) 100 X magnification and (b) 400 X magnification.

As observed in Figures 5 and 6, the thermal treatments used caused the appearance of magnesium precipitates. The precipitation of this element is common when bonded to aluminum, in alloys A356 and 6061 such an element precipitates and in the case of the first alloy this has its hardness increased [12,13].

Figure 7 shows the sample that underwent the solubilization heat treatment, cooled in water, and it is evident that its microstructure has undergone changes in relation to the previous microstructures. There was a reduction in the amount of aluminum precipitates in the form of dark spots and since the solubilization process produces a saturated solid solution, such a solution can be seen clearly in figure 7 b. The sample also presented the β phase in a vermicular format as in the normalized sample, but in a smaller quantity.

As the figure is analyzed, it can be said that there is a solid aluminum solution rich in α phase and saturated in β phase (with greater amount of magnesium). In a work on the characterization of an aluminum alloy bound to copper, a microstructure very similar was found when the solubilization process was applied, the microstructure was named by the author as matensitic [12], naming the microstructure found in ferrous materials that suffered tempering heat treatment.

The microstructure of the last test body is shown in Figure 8, the sample was also subjected to the process of solubilization with cooling in oil. Through the visualization of the microstructure, mainly in Figure 8b, it is concluded that the final microstructure is quite similar to that found in the water cooling process, however it is important to bring to the discussion that a greater amount of the structure is perceived, very similar to martensitic structure in the sample cooled with oil and the ß phase is not noticeable in vermicular format.

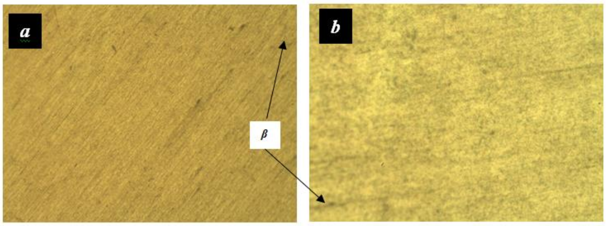

Figure 7: Sample solubilized and cooled in water (a) 100 X magnification and (b) 400 X magnification.

The result found was as expected, as well as in the sample cooled in water, because with the acceleration of cooling there would be a greater increase in the magnesium-rich phase in relation to the one rich in aluminum due to the lack of time for phase transformation [9]. In the sample in Figure 8 it is also possible to see small amounts of magnesium precipitates, also present in the sample cooled in water, in the form of dark spots and a noticeable reduction in the matrix phase, rich in aluminum.

With the display of the four microstructures, it is possible to perceive the presence of certain phenomena. According to the application of heat treatments with more severe cooling, there was a reduction in the α phase, an event that also occurs in heat treatments in bronze aluminum alloys [12]. There was also a reduction in the ß phase in the form of precipitates and a tendency for the appearance of a microstructure visually similar to the martensitic one, as the cooling speed increased.

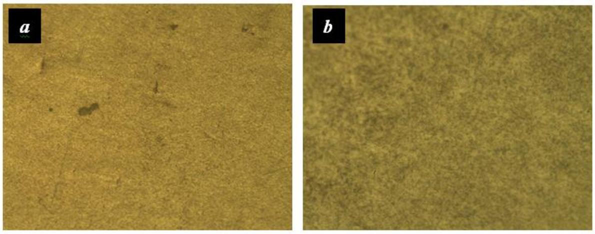

Figura 8: Amostra solubilizada e resfriada em óleo (a) ampliação de 100 X e (b) ampliação de 400 X.

CONCLUSION

Heat treatments have as main objective the microstructural change of the material and consequently its properties. These procedures are commonly used in ferrous alloys that show an evident change in their microstructure, depending on the method used. When dealing with non-ferrous alloys, they can also be subjected to heat treatments and the appearance of microstructural changes can be noticed.

When four samples of 5052 aluminum were subjected to different heat treatments, it was possible to find microstructures peculiar to each heat treatment applied. The first sample was annealed and its microstructure largely presented the α phase (rich in aluminum) and precipitated magnesium in the form of dark spots, which are characterized as the β phase. The second sample was normalized and presented α phase, however the magnesium precipitates in the form of dark spots were found in small amounts in comparison with the annealed sample, in this sample there was the appearance of the β phase in a vermicular form throughout the entire sample. The remaining two samples were solubilized and presented a structure similar to martensitic in steels, which is saturated in the β phase, which has a greater amount of magnesium, however the sample that was cooled in water still showed vermicular forms of the β phase in certain locations, since in the sample cooled in oil, a larger quantity of the β phase can be identified than in the sample cooled in water.

Based on the information previously described, it can be concluded that the application of heat treatments to 5052 aluminum alloys caused considerable changes in the microstructure of the alloy and even the type of cooling used during the procedure was able to lead to such changes, which allows improve mechanical properties and use the same material in different working conditions.

ACKNOWLEDGMENTS

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