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INFLUENCE OF ANNEALING AND NORMALIZING HEAT TREATMENT ON THE MICROSTRUCTURE OF THE WELD JOINT OF THE SAE 1020 STEEL

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Abstract. *There are several welding processes, among them there is the shielded metal arc welding (SMAW). In this process, the union between the metals is achieved by heating them with an electric arc established between a shielded metal electrode and the part being welded. During the welding process there is a microstructural change in the region close to the welded joint, called the heat affected zone, which corresponds to the region that did not melt during welding, but had its microstructure and properties altered by the heat induced during the execution welding. Understanding the microstructural and mechanical changes that occur in the fusion zone, as well as in the heat affected zone (HAZ), are parameters of great importance, because affect the resistance of the welded joint. In this context, the aim of this work is studied SAE 1020 steel welded by SMAW, using AWS E6013 electrode, and subsequently subjected to heat treatment of annealing and normalization. The main results show that there is a considerable microstructural difference between the region of the solidified fusion pool and the HAZ, being constituted by columnar and equiaxial grains, respectively. Microstructural changes were also observed between the samples annealed and normalized.*

Keywords: *SAE 1020 steel, welding, shielded electrode.*

1. INTRODUCTION

Welding is defined as the process of joining two metal parts, using a heat source, the solder being the result of this process. Welding processes are widely used in the manufacture of various products, from metallic structures to space vehicles. Historically, welding processes had a great boost during World War II, due to the manufacture of ships and planes (Wainer et al., 1992).

There are several welding processes that use different forms of energy in order to produce the heat necessary for the occurrence of base metal fusion, among them there are processes that use electric arc as a heat source. The electric arc is formed by passing an electric current between the base metal (metal to be welded) and a metal bar, called an electrode. To form the electric arc, a potential difference considered relatively low is necessary, being 40 to 50 Volts for direct current and 50 to 60 Volts for alternating current (Chiaverini, 1986).

Among the electric arc welding processes there is the one that uses shielded electrodes. In the shielded metal arc welding, the electric arc is established between a consumable metallic electrode, which has a coating layer, and the part to be welded (base metal) (Wainer et al., 1992).

The shielded electrodes consist of a metallic core, covered by a coating composed of organic or mineral materials (Chiaverini, 1986). The type of coating used directly influences the metallic transfer, having an impact on the slag fluidity, average droplet size in relation to the core diameter and on the slag aspect (Wainer et al., 1992).

The electrode coating has several important functions, including: the formation around the electric arc a gaseous environment suitable for the deposition of the addition material; the formation of slag, which protects the melting pool from the action of the ambient air, preventing its contamination; electrical and thermal insulation; direction of the electric arc; metallurgical function, since the coating may contain alloying elements that when cast are inserted in the welded joint (Veiga, 2011).

Due to its great popularity and low cost of acquisition and operation, this process was chosen to use in this work. In addition, this process can be used for welding carbon steels in general. Thus, this work presents the study of SAE 1020 steel welded using shielded metal arc welding and then heat treated, considering the normalization and annealing heat treatments for stress relief, which are normally applied to steels. Thus, the understanding of microstructural and mechanical changes that occur in the weld pool region, as well as in the heat affected zone, are important parameters to be studied, as they directly affect the strength of the weld joint.

2. EXPERIMENTAL

The starting material consisted of 20 samples of SAE 1020 steel, with the following dimensions: 100 mm long, 5 mm thick and 50 mm wide, which were chamfered at 45°.

Shielded metal arc welding was performed using a welding transformer type welding source. A 2.50 mm diameter AWS E6013 coated electrode and 100 A welding current were used.

The specimens were welded at room temperature, where the cut and chamfered plates were joined in two by two, and their beveled sides were placed in contact. The welding occurred in a single pass, as the filling with the deposition metal was adequate for the study in question. After the execution of the welding, the welded joint was carefully cleaned in order to remove all the slag formed.

After welding, the samples were cut to a suitable size and then subjected to annealing heat treatment for stress relief to a temperature of 600°C for 60 min, following cooling in the air. The normalization heat treatment was carried out considering the temperature of 900°C for 60 min, the cooling was in the air.

The metallographic preparation was carried out, consisting of sanding, using silicon carbide sandpaper 220, 400, 600, 800, 1000 and 1200, followed by polishing using polishing cloth and alumina (Al_2O_3). The chemical attack was performed using the Nital 3% reagent. The chemical attack was carried out by contacting the surface of the sample with a piece of cotton moistened in the solution, the attack time varied between 5 and 10 seconds. The characterization was performed using optical light microscopy and Vickers hardness (microhardness). Additionally, grain size measurements were performed on the starting material, annealed and normalized samples, using the Linear Heyn Intercept Method.

3. RESULTS AND DISCUSSION

The results obtained for the characterization of the SAE 1020 steel in the starting condition and in the welded and heat-treated condition is presented below.

3.1 Characterization of starting material

The characterization of the starting material is important to know the material being worked on and to be able to compare the results obtained in the different stages of the work. In this way, the microstructure of SAE 1020 steel was analyzed in its initial condition, which corresponds to that acquired in the local commerce.

According to the microstructure analysis (Figure 1), the presence of pro-eutectoid ferrite and perlite (eutectoid ferrite and cementite) is verified, as expected for steel with low carbon content. With regard to the formed ferrite, the difference between pro-eutectoid and eutectoid ferrite is related to the temperature at which each is formed, with the pro-eutectoid ferrite being formed at temperatures above 727°C, in the two-phase field in the where ferrite and austenite are present (phases $\alpha + \gamma$) and eutectoid ferrite is formed at temperatures below 727°C (CALLISTER JR, 2016).

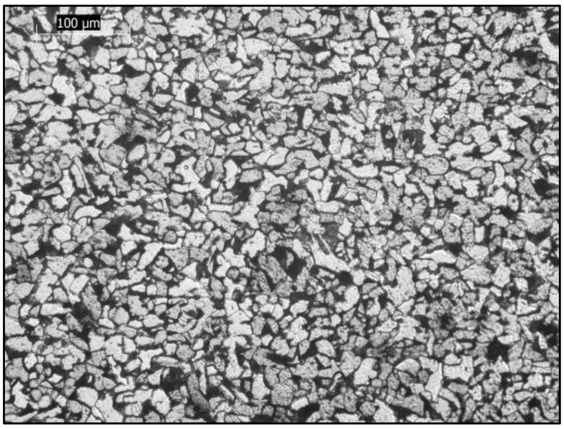

Figure 1. Microstructure of SAE 1020 steel in initial condition.

Regarding hardness, 10 measurements were performed to have a good measurement statistic. The results showed that the starting material has a Vickers hardness of 159 ± 5 HV.

Grain size measurements were taken of the material in the initial condition, using the Heyn Linear Intercept Method. In order to get a good average statistic, about 500 grains were measured. According to the results obtained, the grain size of the sample in the starting condition was equal to 11 ± 2 μm. According to ASTM E 112-96/2004 the ASTM grain size is equal to G10, being considered a small grain.

3.2 Charcterization of welded material

Previously cut and chamfered steel samples were welded using shielded metal arc welding process. For this, the AWS E6013 electrode with 2.5 mm in diameter and a welding current of 100A was used. The welding was performed in a single pass.

The melted zone, which corresponds to the region where the electrode metal and the base metal that fused during welding, mixed and solidified, forming the welded joint. It is observed that the grains are columnar, showing growth from the base metal grains that are on the boundary of the melted zone and the HAZ. In this zone, the grain growth takes place with the same crystalline orientation as the grains in the partially fused region. This type of growth is called epitaxial (Wainer et al., 1992).

Regarding the Vickers hardness measurements, is verified that each one of the regions presented different hardness values. Such values increased as it approached the meted zone. Regarding the hardness of the steel studied in the initial condition and the base metal in the welded condition, is noted that the values are within the standard deviation margin, which confirms that the base metal did not suffer major changes due to heating during the welding. Vickers hardness measurements performed in the different regions of the welded sample. Such measurements were the result of 10 measurements performed, in order to obtain a measurement statistic.

Grain size measurements showed that there was no variation in the grain size of the base metal when compared to SAE 1020 steel in the initial condition. Regarding the grain refining region, despite the measurement values being within the standard deviation range, is visually noted that there is a decrease in the grain size in this area. It was not possible to perform grain size measurements in the other regions observed in the welded sample due to the grain morphology being irregular and difficult to identify the grain boundaries.

Figure 2 shows the microstructures, results of measurements of Vickers hardness and grain size of the different zones of the welded joint.

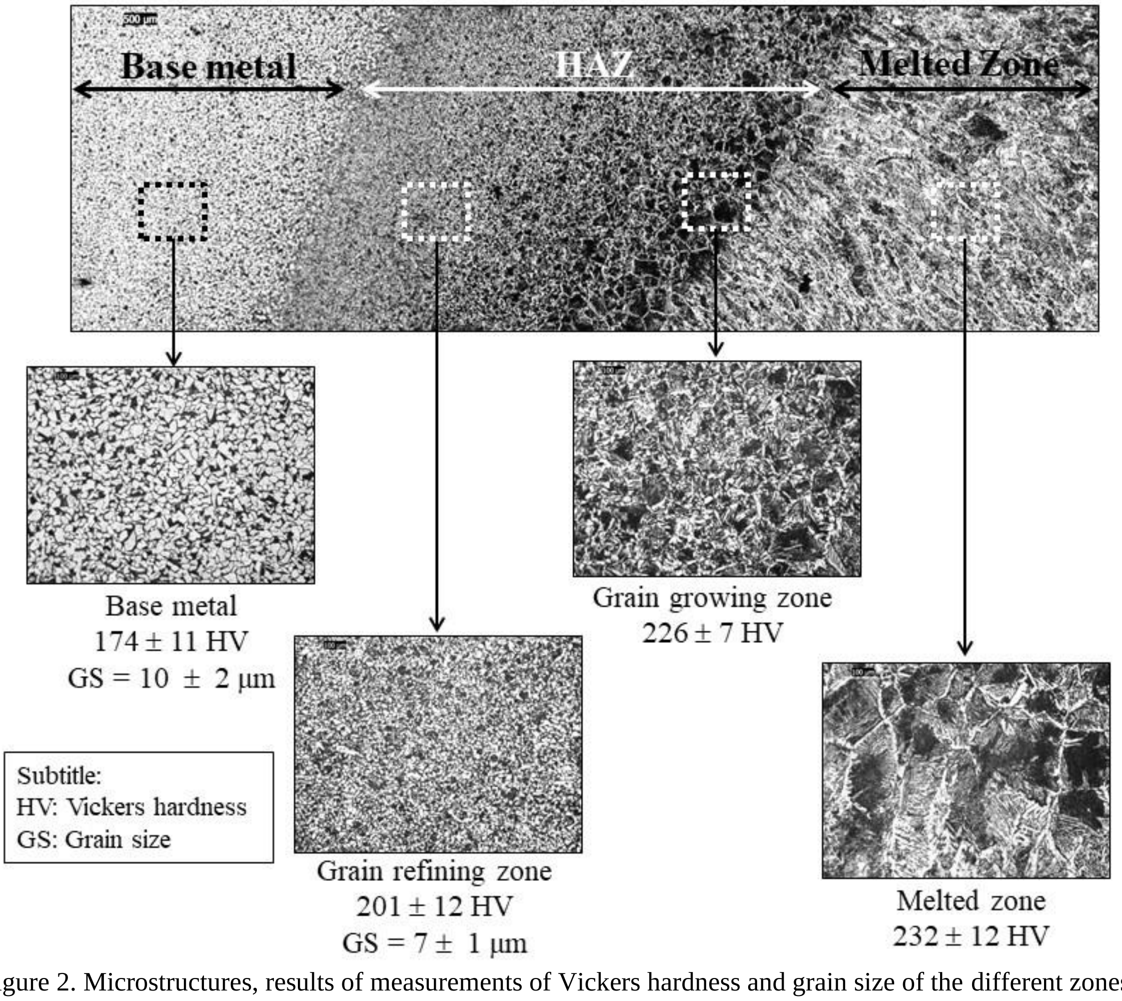

Figure 2. Microstructures, results of measurements of Vickers hardness and grain size of the different zones of the welded joint.

3.3 Charcterization of annealed material

Stress relief heat treatment aims to remove residual internal stresses that can develop in metal parts. To this, the material was heated at temperatures below the critical (727°C), kept at these temperatures for a certain time and then cooled in air.

As observed, the microstructure presented by the welded samples then annealed at 600°C/60 min did not present significant differences in relation to the welded sample. Presenting four distinct regions, referring to the base metal, grain refining, grain growth and melted zone. The morphology presented by the grains did not change, with the base metal and the grain refining region showing equiaxed grains, the grain growing region showed acicular ferrite grains and the grains from the melted zone remained columnar.

It was observed that the base metal and grain refining regions presented the α-ferrite phase and the pearlite microconstituent, not changing the constituent phases as expected, since the heat treatment was below the critical temperature and, therefore, not austenitization of the material occurred for the occurrence of phase transformation in the solid state.

Vickers hardness measurements showed that there was a slight variation in the base metal hardness values, but such variation is within standard deviation limits. Regarding the grain refining region, there was a decrease in hardness values, which occurred the same in the grain growing regions and in the melted zone. As these regions did not show a sharp drop in hardness values, is concluded that there was a slight stress relief at the temperature and time studied.

Grain size measurements revealed that did not variation in the base metal grain size or in the grain refining region. In the other regions was not possible to carry out such measurements, due to the morphology of the grains.

Figure 3 presents the microstructure of the different zones of the welded and annealed at 600°C/60 min, along with the measured Vickers hardness values and the grain size results.

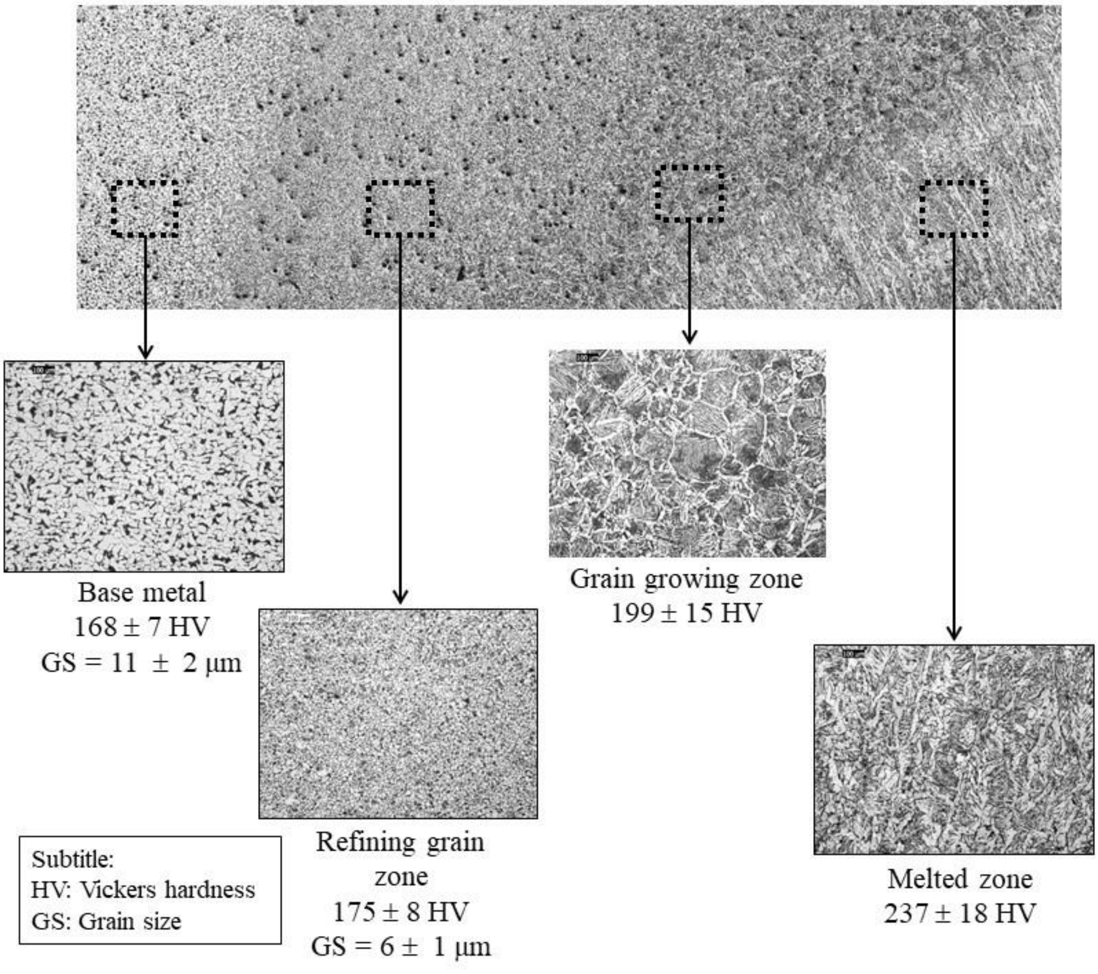

Figure 3. Microstructures of the different zones of the welded and annealed at 600°C/60 min, along with the measured Vickers hardness values and the grain size results.

3.4 Charcterization of normalized material

The normalization heat treatment aims to obtain a homogeneous and refined microstructure. Normalization is carried out by heating the steel to a temperature of 60°C above the upper limit of the critical zone in order to promote full austenitization of the material. Then, air cooling is carried out to room temperature. Due to the fact that the heat treatment temperature exceeds the upper limit of the critical zone, a change occurs related to the phases present in the material, as the austenitic field is reached, which promotes the phase transformation during cooling, according to the degree of cooling used.

Comparing the microstructures of the normalized sample with that of the annealed sample, is verified that the normalization heat treatment, when applied to the initially welded plate, caused significant changes in the different regions now presented by the material, both in the welded and annealed plate. It was noted that the regions referring to the base metal, grain refining and grain growth were replaced by grain region formed by acicular ferrite. The melted zone that presents columnar grains, after normalization is shown with equiaxed grains.

Hardness measurements showed that there was a drop in both the HAZ and the melted zone. This drop is related to the higher temperature supplied to the material and also to the phase transformation that occurred, mainly in the melted zone, which started to have equiaxed grains and no longer columnar, as observed in the welded and annealed samples. Comparing the results of the hardness measurements of the normalized sample with those of the annealed sample, there is a sharp drop in such values, indicating that in the normalization, in addition to the occurrence of grain refining, there is also a decrease in the hardness of the material.

Grain size measurements show that there is a tendency for the equiaxed grain size of the melted zone to increase. It was not possible to perform grain size measurements in the region identified as HAZ of the normalized samples due to the difficulty in identifying the grain boundaries of acicular ferrite.

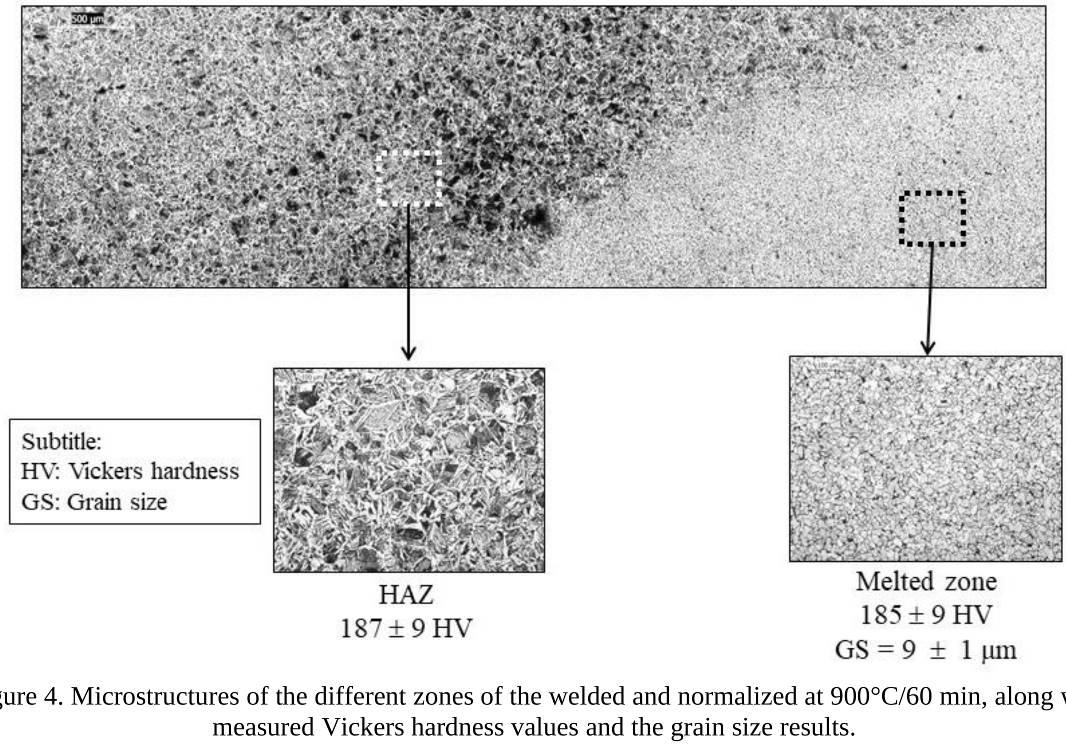

Figure 4. Microstructures of the different zones of the welded and normalized at 900°C/60 min, along with the measured Vickers hardness values and the grain size results.

4 CONLUSIONS

The welded samples presented distinct regions corresponding to the base metal, HAZ and melted zone, each one presenting a different microstructure. The base metal grains were equiaxed, as well as the material in the initial condition. The grains of the melted zone are columnar and the HAZ was divided into two parts, one of them with equiaxed refined grains and the other with coarse grains of acicular ferrite.

Comparing the results obtained for the annealed and normalized samples, was found that the normalization caused more drastic changes in the microstructure of the different regions presented by the welded material and also by the annealed material.

Regarding the Vickers hardness measurements, there was a sharp drop in the values of the normalized sample, which indicates that during normalization, in addition to the occurrence of grain refining, there is also a decrease in the hardness of the material.

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6 RESPONSIBILITY NOTICE

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