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Study on the electric arc of GTAW process

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Abstract. The electric arc is the most used heat source in the fusion welding of metallic materials, since it presents an optimum combination of characteristics, as a result, the processes of arc welding have a great industrial importance, being used in the manufacture of the most varied components and structures and in the recovery of many parts. Many factors are observed in the arc, such as the behavior with the tension, its profile (area), emitted luminosity and thermal efficiency, all of which factors will influence the characteristics of the welds produced. Thus, the objective of this work is to evaluate the characteristics of the electric arc of the GTAW welding process. For this purpose, the arc characteristic curves, its profile (where the measurement of its area was sought) and its emitted luminosity were analyzed. In addition, the thermal efficiency and the heat input from the process were also measured with the help of a continuous flow water calorimeter. The results obtained demonstrated a relationship with data observed and disseminated in the literature.

1. Introduction

A process that makes use of the electric arc as an energy source for the fusion of the materials to be welded is GTAW (Gas Tungsten Arc Welding) also called TIG (Tungsten Inert Gas).

One way of studying the arc is through its dynamic response in operation, surveying the voltage-current relationship (static characteristic curve). The characteristic curve of the arc differs from the curve of a common resistance, for which the Ohm's Law ($V = RI$) is valid, which has the shape of a straight line passing through the origin. The curve of the arc passes through a minimum voltage value for intermediate welding current values, increasing both for larger and smaller currents [1]. These arc characteristic curves are very important because they indicate, for a given operating condition, the average values of welding current and arc voltage required for its operation, which must be supplied by the energy source being used [2].

Another important point to be evaluated in the welding arc is its profile. According to Middel and Den Ouden (1998) [3], changes in this profile can induce variations in arc temperature and pressure allowing significant variations in weld penetration.

It is also possible to relate the aspects of the profile of the arc with the emitted luminosity and the thermal efficiency of the process. Richardson (1989) [4] attributes to this radiation losses in the arc column, which may influence the thermal efficiency of the process. In addition, we can relate the effects observed in the welds with the arc luminosity, and according to Gonzales et al. (1997) [5], the increase in radiation implies more energy sent out of the arc and this causes a decrease in the temperature of the central regions of the arc, reducing the penetration in the welds. These losses can still be directly related to the arc temperature and can be related to the effects evaluated in the thermal efficiency of the welding process.

In this way, the main objective of this work was to study the electrical arc of the GTAW welding process, observing the characteristics of the electric arc, such as operating voltage, profile, luminosity and thermal efficiency.

2. Materials and methodology

All the tests proposed in this work were performed by the conventional GTAW process (source in constant current mode) with CC- polarity and without addition metal. The electrode used was pure tungsten and for the gas, 99.98% argon was used.

2.1. Acquisition of characteristic curves

In order to obtain the arc operating voltage, a welding data acquisition system - IMC SOLDAGEM, model SAP V4 (duly calibrated by the manufacturer) was used in conjunction with the SapTiV4.37s software of the same brand.

For this study, it was used the protection gas as supplied by the manufacturer, i.e. normal working temperature. The methodology followed in this stage aimed at the reproduction of characteristic curves presented in the literature [6]. In this way, the voltage acquisition procedure was started with a top current of 150A, and the subsequent ones in intervals of 10A until the final value of 10A.

All this study was carried out in a copper-based refrigerated block and the parameters kept constant during the tests are as follows: arc length = 4mm; electrode sharpening angle = 60°; electrode diameter = 1.6mm; volumetric flow = $6\,\mathrm{l/min}$ and nozzle number 4.

2.2. Profile

Profiles of the electric arc were observed using a digital camera. For the image acquisition, care was taken as presented in the literature and expressed by Vilarinho [7].

In order to protect the camera from the high luminosity generated by the arc, a light filter for level mask 14 was used. The images were acquired along with obtaining the voltage-current data, however the range of variation between each image acquisition was of 20A. The images obtained in this procedure were transported to the free software ImageJ, to measure the arc area.

2.3. Luminosity

For the accomplishment of this experiment it was used a digital lux meter of the brand Minipa model MLM-1020. The apparatus accompanies the software responsible for data acquisition, the values obtained being represented in the lux unit and the acquisition interval is one point every second. The relative accuracy of the acquisition is $\pm 0.75\%$ in reading, i.e. $\pm 3\%$, which is provided by the manufacturer.

The arc luminosity was acquired in the block cooled with predetermined currents (120, 100 and 50A). For this test, the lux meter was positioned at a fixed distance from the electric arc (6cm) and protected by a level 6 solder mask light filter.

2.4. Thermal Efficiency

The calorimeter used in this work followed the principle of that proposed by Lu and Kou [8] and similar to that used by Sgarbi [9], being a continuous flow, as shown schematically in Figure 1. This calorimeter was used due to the good results presented for the acquisition of efficiency in the GTAW welding process, besides its easy construction and use.

For the surface of the calorimeter, a phosphor copper tube CA-122 was used, the water temperature measurements were performed with temperature sensors DS18B20 that has an accuracy of ± 0.5°C and an update time of less than 750ms and the flow rate with a 1/2 (SEM-HZ21WA) flowmeter and $\pm 10\%$ accuracy. The flow measurement was performed near the water inlet in the calorimeter and kept as constant as possible during the tests at a rate of approximately $9\,\mathrm{l/min}$.

For the execution of the experiments a mechanized conduction system was used, with the welding torch with displacement angle and neutral work. The set arc time was approximately 90 seconds for all tests and constant welding parameters, as presented in section 2.1. The currents used were: 100A and 120A. In addition to the calorimeter tests, the instantaneous current and voltage values were acquired, according to section 2.1.

Five tests were performed for each of the operating currents used, that is, 100A and 120A, with the main objective being to obtain a mean, confidence level and the standard deviation between the values obtained.

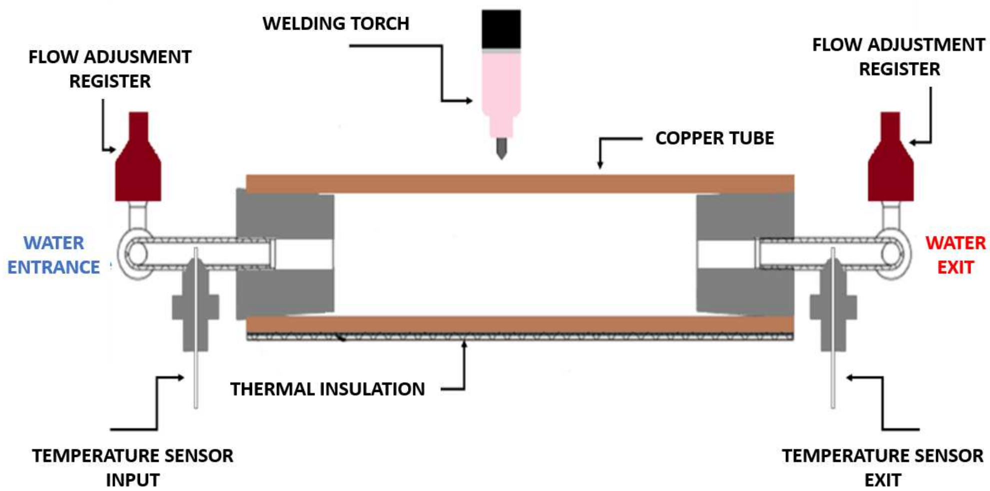

Figure 1. Current dilution plot for conventional electrodes and polymer agglomerated electrodes.

3. Results and discussion

3.1. Curves Voltage - Current

The voltage-current values obtained are shown in Figure 2.

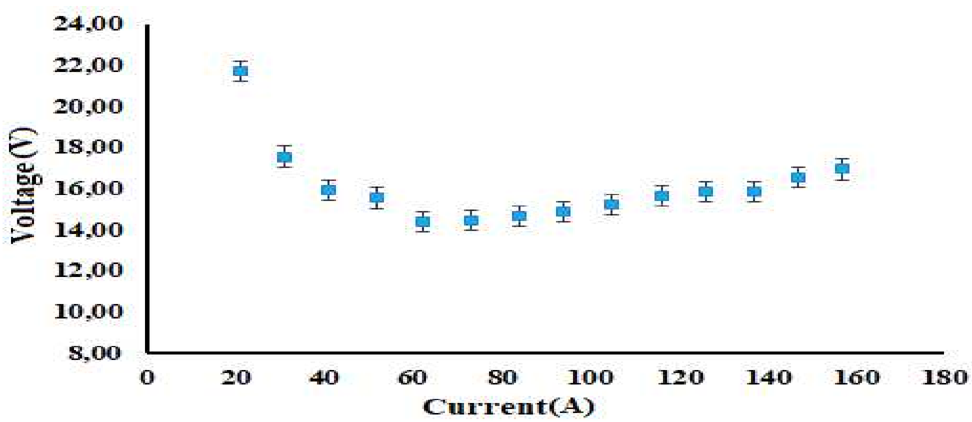

Figure 2. Voltage-current ratio for the GTAW welding process.

It can be observed that this curve is different from that expected for a common resistance, for which the Ohm Law (U = Ri, with constant R) is expressed as a straight line passing through the origin. The characteristic curve of the arc has a minimum voltage value for intermediate current values. For higher or lower currents, the voltage tends to increase. The increase in voltage for small current values is linked, in part, to the reduction in the temperature of the arc gases due to the smaller amount of energy generated in the arc. Lower temperatures imply less ionization and thus greater resistance to the passage of electric current.

The position and shape of the characteristic curve depend on numerous factors such as the size, shape, material and temperature of the electrodes, composition and pressure of the protection gas and the length of the arc.

3.2. Profile of the arc

Figure 3 shows the arc images for the larger nominal currents, that is, from 150A to 50A. Figure 4 shows the arc profile for the 20A and 30A currents.

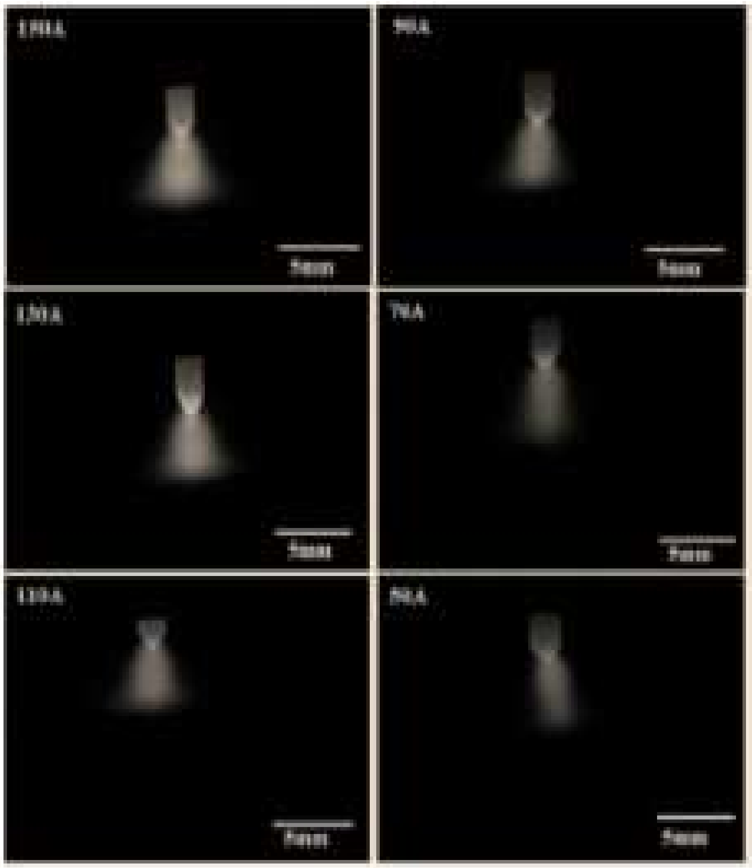

Figure 3. Images of the electric arc in relation to the nominal current.

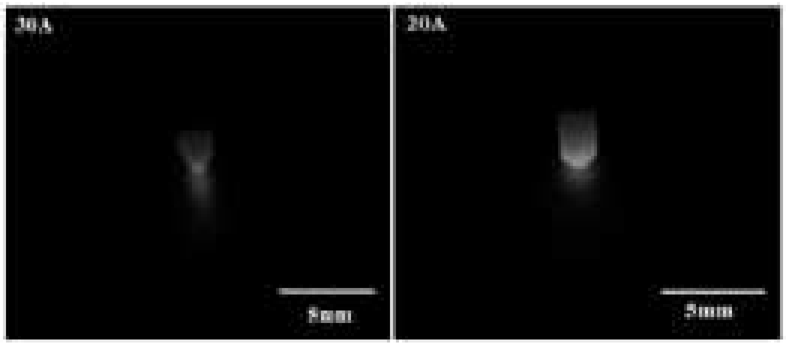

Figure 4. Images of the electric arc for the lower currents.

In order to better expose the properties of the electric arc, Figure 5 shows the relation between the nominal current as a function of the arc area.

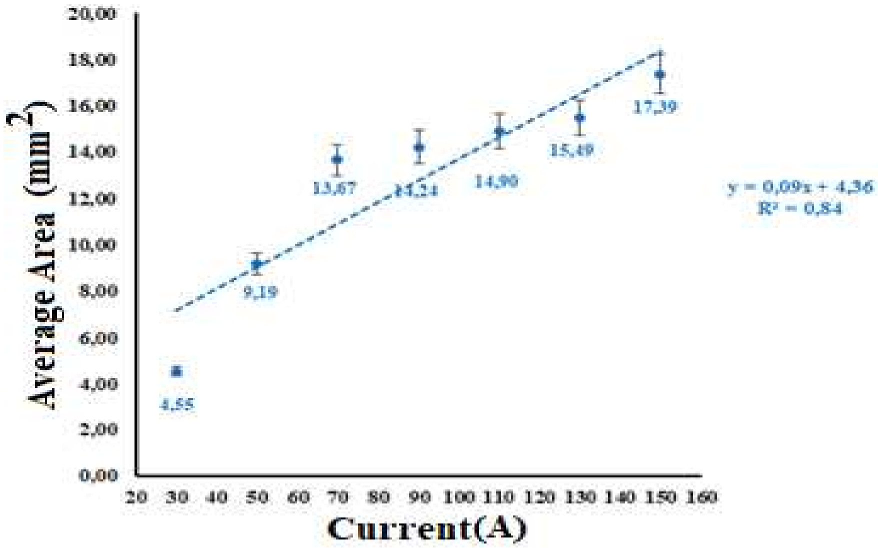

Figure 5. Area of the electric arc measured by the Image J software as a function of the nominal current.

3.3. Luminosity of the electric arc

This result is shown in Table 1 and plotted on the graph of Figure 6 for three different currents. Through these data, we see a gradual decrease in brightness as the welding current has decreased.

Table 1. Data acquired for the brightness of the GTAW process arc.

I nominal (A)	Average brightness (Lux)	Deviation Standard
120	233.43	4.32
100	200.23	3.34
50	66.52	2.76

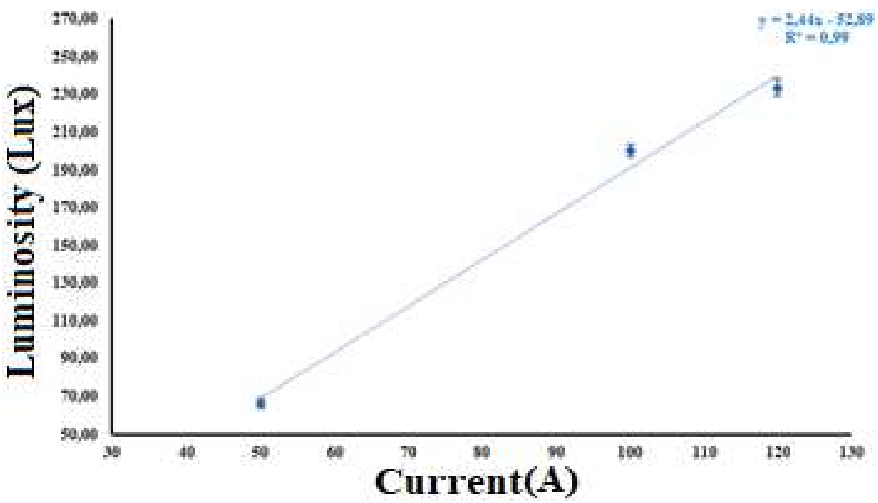

Figure 6. Graph of the arc brightness ratio as a function of the GTAW process operating current.

Richardson [4] points out that this radiation is associated with losses in the arc column, which may influence the thermal efficiency of the process. Other authors complement that the amount and type of radiation emitted by the electric arc depend on the atomic mass and the chemical structure of the gas, the temperature and the pressure. The predominant radiation results from atomic excitation and ionization. Higher ionization states occur as the arc energy increases, resulting in higher energy levels [10].

The results obtained are coherent according to the literature [11], which states that the luminous intensity emitted by the welding arc can be altered in several ways during welding, among which we can mention the modification of the currents, the length arc, voltage and plasma radius.

In order to obtain the radiant energy equation of the arc column several approximation laws must be applied, such as the Kirchhoff Law, Rayleigh-Jeans, Elenbaas-Heller, and Ohm's Law [12]. By this relation, Li and Zhang [13] created a theoretical model, "Model of Arc Light Sensing", which makes correlation between the electric arc light radiation and the welding parameters. Through it we see that this radiation does not depend only on temperature, but also on the density of mean current and thermal conductivity. With this model it is possible to understand the phenomena associated with the radiation of the arc and the light of the arc.

3.4. Thermal efficiency

The data obtained by the calorimetry tests were plotted in Figure 8, with the tests 1 to 5 performed with 100A operating current and the other tests, from 6 to 10, with 120A. To better analyse the results obtained in this one Figure 7 shows the thermal efficiency data of the GTAW welding process obtained by other authors during the years.

Together, Stenbacka [14], shows the effect of the base material used in the calorimeter (anode) on thermal efficiency, being presented in Table 2 values obtained by other authors.

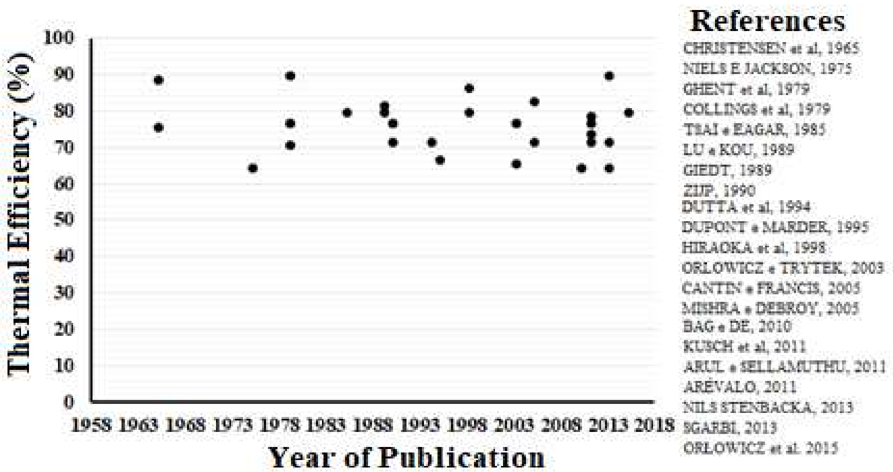

Figure 7. Average thermal efficiency of the GTAW welding process reported by several authors.

Table 2. Results of studies on thermal efficiency of the GTAW process collected by the author of Stenbacka [14].

Material	Efficiency, η(%)
Copper anode	80-90
Stainless Steel 360L	79-84
Steel A36	62-72

Analyzing the data of Figure 8 and Table 2, it can be seen that the thermal efficiency of the welding process was in the range of approximately 60 to 90%, being influenced not only by the welding parameters employed, but also by the material used as the base of the calorimeter [14]. The values indicated in the literature were used to validate the constructed calorimeter.

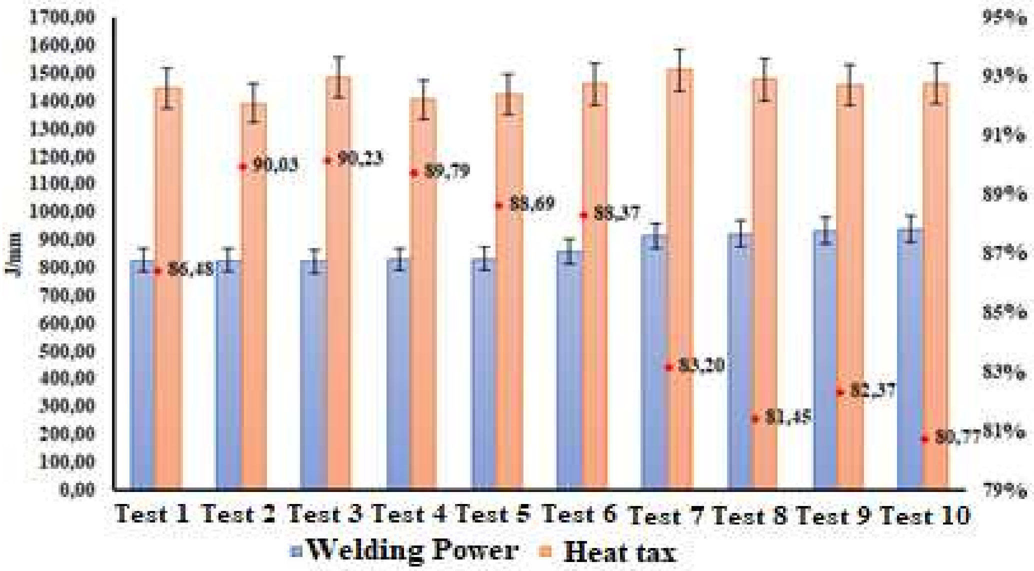

Figure 8. Calorimetry results obtained for the welding process.

For the tests proposed in this work, an average thermal efficiency of 89 and 83% was observed for the operating currents of 100A and 120A, respectively. The results obtained are very close to those presented in the literature (Figure 7), which is very close to the values of authors who used copper specimens, that is, thermal efficiency between $80 - 90\%$ (Table 2) [15,16]. The results that were obtained in this work are superior to those reported in studies that used steel, aluminum or stainless steel test specimens, for example, Ghent et al [17] with 71% efficiency, Arévalo [18] with 70%, Cantin and Francis [19] obtained mean values of 83% and Giedt et al [20] with 82% when using 304L stainless steel base. This difference between the results shows that the base material directly influences the heat transfer to the part during welding, a fact also verified by Sgarbi [9] in his work.

By analyzing the tests in which the welding parameters were kept constant and only the welding current changed, a lower thermal efficiency of the arc was observed for a higher welding current. This effect was also mentioned by Niles and Jackson [21], Arévalo [18] and Sgarbi [9]. Due to the static feature of the source, increasing the welding current causes the welding voltage to increase as well. In tests 1 to 5 the mean voltage was 14.7V, while in the tests 6 to 7 this was 15.8V and the difference between the arc yields in the two processes was approximately 6%. According to [18] the consequent decreases in thermal efficiency are applied to the higher heat losses in the arc column than the energy produced by the voltage expansion, which is directly influenced by the dimensions of the plasma column. It can still be related that a larger contact area of the plasma column with the environment generates greater heat exchange with the environment [18]. Therefore, the increase in welding current has a negative effect on the thermal efficiency of the GTAW welding process.

4. Conclusions

The static characteristics, profile and luminosity of the arc followed the expected and as attributed by the literature. Also, results obtained for the thermal efficiency for the GTAW process presented good repeatability and coherence with values present in the literature. Additionally, changes in thermal efficiency were observed when the current was added, as well as changes in voltage.

Acknowledgments

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