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ANALYSIS OF THE SHARPENING ANGLE IMPACT UNDER THE USEFUL LIFE OF THE TUNGSTEN ELECTRODE USED IN AUTOMATIC TIG CLAD WELDING PROCESS

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Abstract. *In this paper the TIG welding process (Tungsten Inert Gas) is used to cladding parts with Alloy 625 (Inconel® 625 - Ni/Cr/Mo alloy). The behavior of the tungsten electrode was analyzed during an automatic process, changing the variables that have direct presence in its efficiency: sharpening angle, the flap at the tip of the electrode, and the inert gas flow that was used. The parts used as specimen were made of AISI 4130 80K Steel, and the electrode was the 4,0mm diameter Lanthanum 2%. The main aim was to seek the understanding of what would be the set composed by these three variables, that would provide a greater useful life for the electrode, this way reducing the sharpening times to which the electrode is subject and, as a consequence, reducing consumption and setup time. The analysis was made through DOE, with the help of Minitab 16. The results value collected correspond to the useful lifetime of each sharpening executed on the electrode tip, where the useful life limit was defined through the visual inspection of the weld bead deposition quality. As a consequence of this result, variables were known that can be considered essential to achieving this goal, and it was even possible to notice the influence of a variable with extreme importance to the execution of the process, but with no influence over the useful life of the electrode.*

Keywords: *Useful life, Sharpening, Tungsten Electrode, DOE.*

1. INTRODUCTION

The Gas Tungsten Arc Welding (GTAW) process, commonly referred as TIG welding, makes use of a non-consumable tungsten electrode to support the arc, protected by a gas that creates a protective atmosphere. This process can be used in all welding positions for joining and cladding different alloys (AWS, 1991).

Small amounts of oxides and other elements are used to make the tungsten electrodes. The American Welding Society (AWS) specification standardizes the alloys and other characteristics of tungsten welding electrodes (AWS A5.12 / A5.12M). In this way, there are different dimensions and characteristics of the electrodes, which are chosen according to their application.

Different studies involving Welding TIG process address the importance of tungsten electrode sharpening on the final result of the activity. Different approaches are found, from the influence of the angle on the penetration of the weld, the direction of sharpening in relation to the axis of the electrode and methods of execution. However, few approaches are found around the impact of the chosen angle on the useful life of this consumable used in the process.

Different authors report results about different analyzes carried out in what concerns studies on the sharpening of the tungsten electrode during the TIG welding process. Fontana (1986) reports about influence of the sharpening angle on the width of the bead, Kou (2002) reports in its results that width is reduced with the increase of the angle of the electrode. Erohen (1971) indicates that reducing the diameter of the electrode tip increases the current density, which consequently leads to increased penetration. Key (1990) showed results that coincide with those presented by Fontana and Kou, but are opposite to those of Erohen, that is, the smaller the diameter of the tip of the electrode, the shallower the penetration becomes .

According to Niles and Jackson (1975) the electrode sharpening angle, in addition to the effects mentioned above, has a significant influence on the arc voltage.

Unlike union welds, for clad welding applications the penetration on the base metal isn’t a prerequisite, thus exempting the importance of the grinding angle for this focus. The objective on the Clad welding is only the correct fusion between both materials.

However, practical experiments show that depending on the chosen angle the useful life of the electrode is changed exponentially, and represents a direct impact on process costs and productivity, given the time spent to setup the equipment. This application is valid when some technical choices are performed correctly, such as: welding current, electrode diameter and class, heat input and purity level of the inert gas used. The Tungsten Guidebook (2013) describe the geometry of preparation of tungsten electrode, according is shown in the Fig 1.

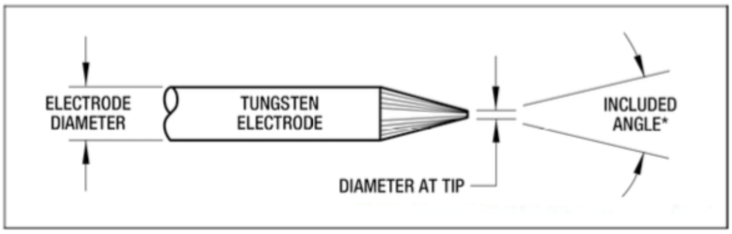


Figure 1. Electrode Geometry (from Tungsten Guidebook, 2013)

2. TIG WELDING PROCESS

A schematic illustration of the TIG welding process is shown in Fig. 2. The tungsten electrode (non-consumable and protected by inert gas) is used to form an electric arc with the base metal. The heat input generated by the electric arc is responsible for generating the weld pool between the metals that are being welded.

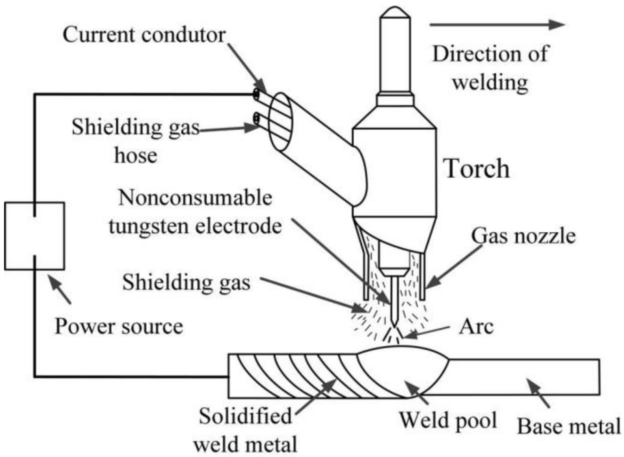


Figure 2. Illustration of GTAW Process (from Zhang et al, 2012)

Kumar et al (2015) describe in a simplified way in their study, the geometry of weld bead deposited by the Clad Welding Process that is composed by penetration, bead height, bead width and toe angle. The detailing of the weld bead profile is shown in Fig. 3.

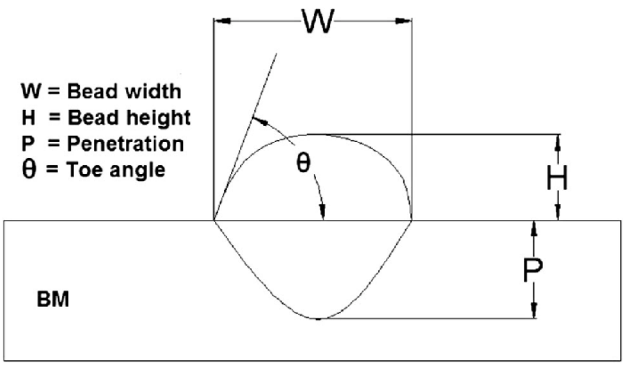


Figure 3. Schematic diagram of weld bead geometry (from Kumar et al, 2015)

3. SELECTING AND PREPARING TUNGSTEN ELECTRODES

3.1 Dimensional choice and material of electrodes

Choosing a specific type of tungsten electrodes to TIG weld application depends of basic information, but with high relevancy to quality, productivity and costs of process. The tungsten electrodes come in variety of diameters – typically ranging from 1,0 to 4,8 mm – and length of 175 mm. The electrodes are composed either of pure tungsten or a hybrid tungsten and other rare earth elements and oxides. Each electrode is color-coded, with the color appearing at the tip of each electrode. The Fig. 4 shows the specifications of tungsten electrodes, reported in the studies of Dobránszky et al, (2005).

Designation	Alloying (wt-%)	Color code
WP	Unalloyed	Green
WC20	CeO_2=1.80-2.20	Gray
WL10	La_2O_3=0.90-1.20	Black
WL15	La_2O_3=1.30-1.70	Gold
WL20	La_2O_3=1.80-2.20	Sky-blue
WT10	ThO_2=0.80-1.20	Yellow
WT20	ThO_2=1.70-2.20	Red
WT30	ThO_2=2.80-3.20	Violet
WT40	ThO_2=3.80-4.20	Orange
WY20	YtO_2=1.80-2.20	Blue
VX	Combined oxides	Yellow-green
WZ3	ZrO_2=0.15-0.50	Brown
WZ8	ZrO_2=0.70-0.90	White

Figure 4. Specification of tungsten electrodes according to ISO 6848 specification (from Dobránszky et al, 2005)

Diameters and Lengths: Tungsten Electrodes are available in a variety of standard diameters and lengths. The most commonly used diameters are shown in Tab. 1.

Table 1. Standard diameters of tungsten electrodes (from thefabricator.com, 2008)

U.S. Customary Measurements	Metric Measurements
.040"	1.0 mm
1/16" (.062" and .060")	1.6 mm
3/32" (.093")	2.4 mm
1/8" (.125")	3.2 mm
5/32" (.156")	4.0 mm
3/16" (.187")	4.8 mm

3.2 Electrode Tip Geometry

According Sewel (2004), the essential features of electrode geometry are taper and, with truncated electrodes, diameter at tip. In general, large angles and tip diameters offer long life, better penetration, a narrower arc, and the capability of sustaining more current without erosion. Smaller angles and smaller tip diameters result in less tendency for arc wander, give a wider and more stable arc, and can be used at lower currents.

The repeatability of both features is mandatory if consistency of weld deposition is to be realized, and this is where recognition of the advantages of employing a tungsten tip grinding machine must be realized.

The alternative of manual preparation by the welder brings with the probability not only of inconsistent geometry from electrode to electrode but the introduction of significant deviations from the optimum as shown in Fig. 5. These deviations may result in errant tip geometries, such as:

- An axially displaced tip;
- An irregular cone;
- A non-square truncation;
- A variation in tip diameter;

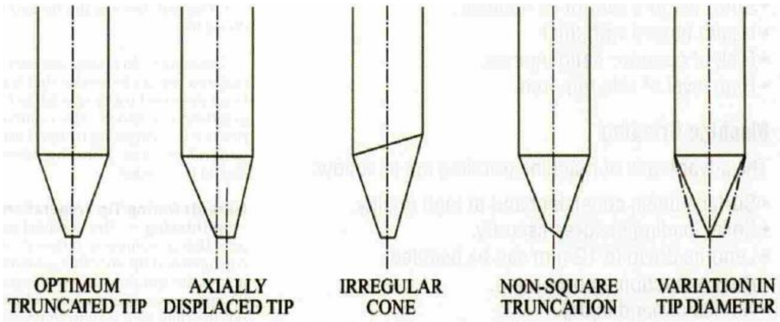


Figure 5. Common potential deviations from optimal tungsten tip grinding geometries (from Sewel. 2004)

3.3 Taper Grinding

According to the Tungsten Guidebook (2013), the shape of the tungsten electrode tip is an important process variable in precision arc welding. A good selection of tip/flat size will balance the need for several advantages. The bigger the flat, the more likely arc wander will occur and the more difficult it will be to arc start. However, increasing the flat to the maximum level that still allows arc start and eliminates arc wonder will improve the weld penetration and increase the electrode life.

Electrodes for DC welding should be ground longitudinally and concentrically with diamond wheels to a specific included angle in conjunction with the tip/flat preparation. Different angles produce different arc shapes and offer different weld penetration capabilities.

The most important element of proper taper grinding is that the electrode must be ground longitudinally (lengthwise). Grinding electrode tips crosswise has a negative effect on the stability and formation of the arc at the electrode tip. Tungsten electrodes are manufactured with the molecular structure of the grain running lengthwise and thus grinding crosswise is "grinding against the grain." More importantly, electrons flow at a greater density on the surface of the electrode. If electrodes are ground or polished crosswise, the electrons have to jump across the grinding marks. The arc begins before the tip, spreads out, and usually wanders. The tungsten electrode becomes overheated and wears out more quickly. By grinding longitudinally with the grain, the electrons are led steadily and with less difficulty to the extreme tip of the tungsten electrode. Figure 6 provides an example of correct and incorrect grinding.

Abid et al (2013) concluded in their simulated studies that the heat flux in the tip region of the electrode is affected by the angle of the electrode tip. The authors report that decreasing the angle of the tip this flow is greater and when this angle is increased, this flow decreases

Figure 6. Correct and Incorrect Grinding (from thefabricator.com, 2008)

3.4 Gas Flow

Kah, P. & Martikainen (2013) describes the use of the Weld shielding gas as the element responsible for removing the reactive gases near the region of the weld, thus avoiding the harmful effects that these can cause on the deposited material.

Bitharas et al (2016) cited that in order for the gas protection to be effective, gas flow must be considered. The flow should be strong enough to move the air away from the weld area and thus protect the welding pool; however, a high flow rate can cause turbulence in the gas flow, resulting in defects in weld bead and arc instability, not to mention the higher cost of welding.

The ideal flow takes into account factors such as; type of gas used; distance between nozzle and workpiece; type and position of the torch; joint type; nozzle diameter; speed and welding position; type of metal to be welded and size of the welding pool. Torch adaptive devices are available on the market that allow for smoother and more efficient gas flow. A rule to determine the ideal flow rate is to test, starting with high flow rate and decreasing gradually until a superficial oxidation of the cord begins; the ideal flow rate will be the closest and superior to that.

4. EXPERIMENTAL PROCEDURE

The objective of this study is to evaluate the electrode useful life in different configurations of tip sharpening angle, flap dimension and gas flow. The electrode used has 1.5% Lanthanated (gold) with Ø4,0 mm. The machine used for welding is Fronius FPA9000, the material deposited is the Inconel 625 (Ni / Cr / Mo) and the base metal is SAE 4130 with 80K. The welding process was performed with Alternating Current (AC), table speed of 30 cm / min and welding speed of 250 cm / min. The values of gas flow, sharpening angle and flap dimensions were used according to the values shown in Tab. 2.

To validate the best parameters to the process and identifying the optimum operating conditions, a DOE was used to plan the experiments. DOE is a technique for understanding variability, in which factors are systematically and simultaneously manipulated while the variability in outputs (responses) is studied to determine which factors have the biggest impact.

To start the process, a DOE was planned for optimizing the process/machine parameters. The staffs and operators of the process conducted a series of brain storming sessions to identify the important parameters for experimentation. The parameters selected through these discussions were gas flow, three different sharpening angle and diameter at tip. Since the relationship between these parameters was not known, it was decided to experiment all these parameters at complete factorial planning. The values to be varied were previously discussed with the application technical team, and inserted in Minitab 16 so that the variations were crossed and the sequence of tests defined.

Table 2. Process parameters and their levels (from the authors, 2017)

Influences	**Factor**	**levels**		
1	Diameter at tip (mm)	0,5	0,8	
2	Sharpening Angle	22,5°	30,0°	35,0°
3	Gas Flow (l/min)	16	20	24

As per the design layout given in Tab. 2, the experiments were conducted after randomizing the sequence of experiments, and the data were collected and analyzed by Taguchi's Signal-to-Noise ratio method. The ratio can be treated as a response (output) of the experiment, which is a measure of variation when uncontrolled.

Figure 7 show the combinations to be executed the tests according crossing all the variables shown in Tab. 2.

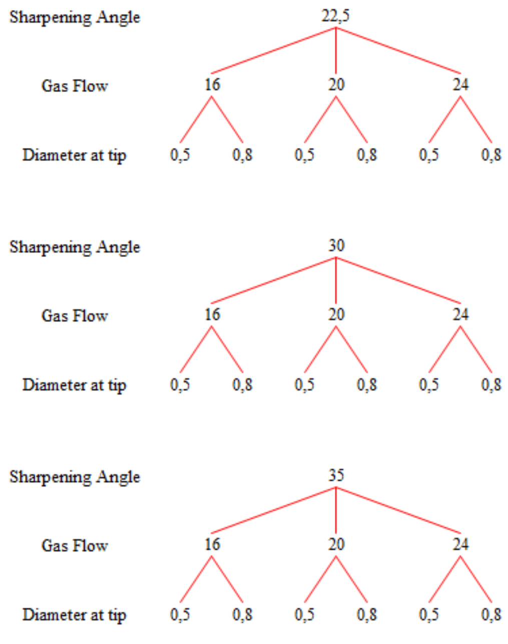


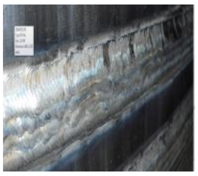
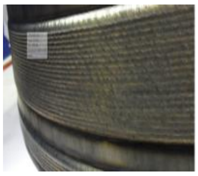
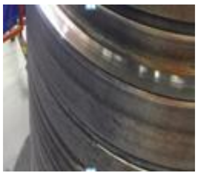
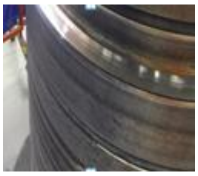
Figure 7. Combination of parameters to execute tests (from the authors, 2017)

As previously mentioned, the useful life limit of the electrodes was evaluated according to the visual quality of the welded surface, using the same qualified inspector according to the norms in force to perform this activity.

5. RESULTS AND DISCUSSIONS

Table 4 shows the main results (two worst and three best results achieved during visual inspection of quality of profile welded and conditions of tungsten electrode) at final of useful life. The evaluation criterion was the visual inspection of welding, according applicable rules, so the same evaluator was maintained so that there weren't differences in the interpretation of quality of weld bed.

Table 4. Result of superficial quality after welding (from the authors, 2017)

				
				
Low Performance	**Medium Performance**	**High Performance**	**High Performance**	**High Performance**
Sharpening Angle 22,5° Diameter at Tip 0,8mm Gas Flow 16 l/min	Sharpening Angle 22,5° Diameter at Tip 0,5mm Gas Flow 20 l/min	Sharpening Angle 30° Diameter at Tip 0,5mm Gas Flow 20 l/min	Sharpening Angle 30° Diameter at Tip 0,5mm Gas Flow 24 l/min	Sharpening Angle 35° Diameter at Tip 0,5mm Gas Flow 24 l/min

The answer required after tests, was the welding time achieved until it reaches the end of tungsten useful life. The final values (in minutes) are shown in Tab. 5.

Table V. Experimental Results (from the authors, 2017)

FACTORS			ANSWER
Sharpening angle	Diameter at Tip	Gas Flow	Welding time (minutes)
22,5°	0,5mm	16 l/min	107
22,5°	0,5mm	20 l/min	307
22,5°	0,5mm	24 l/min	143
22,5°	0,8mm	16 l/min	83
22,5°	0,8mm	20 l/min	151
22,5°	0,8mm	24 l/min	144
30°	0,5mm	16 l/min	285
30°	0,5mm	20 l/min	897
30°	0,5mm	24 l/min	1290
30°	0,8mm	16 l/min	180
30°	0,8mm	20 l/min	320
30°	0,8mm	24 l/min	1150
35°	0,5mm	16 l/min	140
35°	0,5mm	20 l/min	330
35°	0,5mm	24 l/min	1440
35°	0,8mm	16 l/min	95
35°	0,8mm	20 l/min	110
35°	0,8mm	24 l/min	980

The main effect (the change in average response produced by factor of interaction - impact degree to which the effect of each characteristic is able to impact in one or more factors) plots of the values were made with the help of Minitab statistical software and are presented in Fig. 6 and Fig. 7. From these plots, the best values for parameters were identified as the level corresponding to highest value (time - in minutes). Thus, the best levels were selected from the interaction plot and the values the main effect plot provided information for analysis of the impact that each of the previously selected variables is capable of causing on the life of the electrode during the coating welding process in an automatic TIG process. The interactions between factors are show in the Fig. 8 and 9.

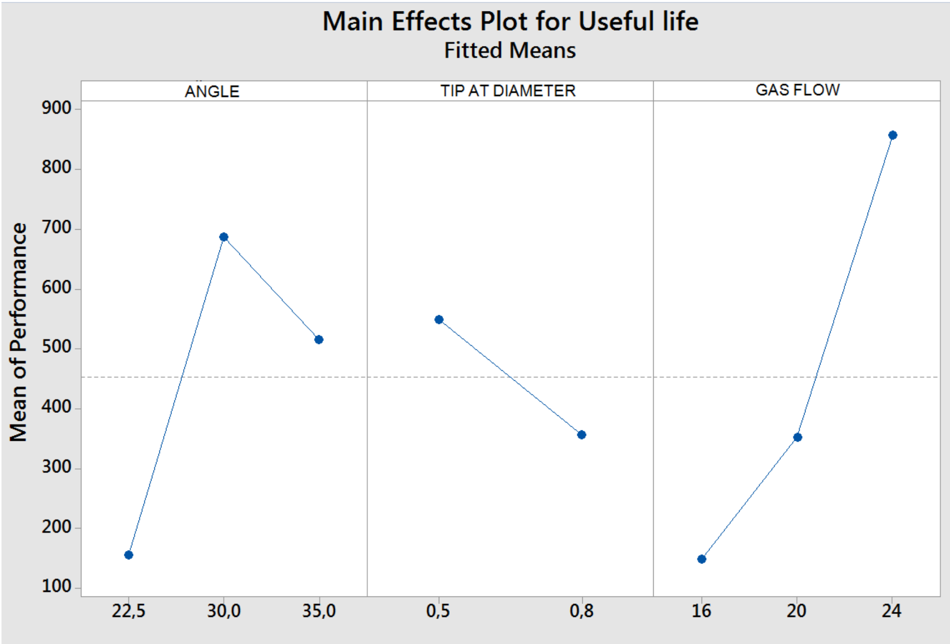


Figure 8. Main effects Plot (from the authors, 2017)

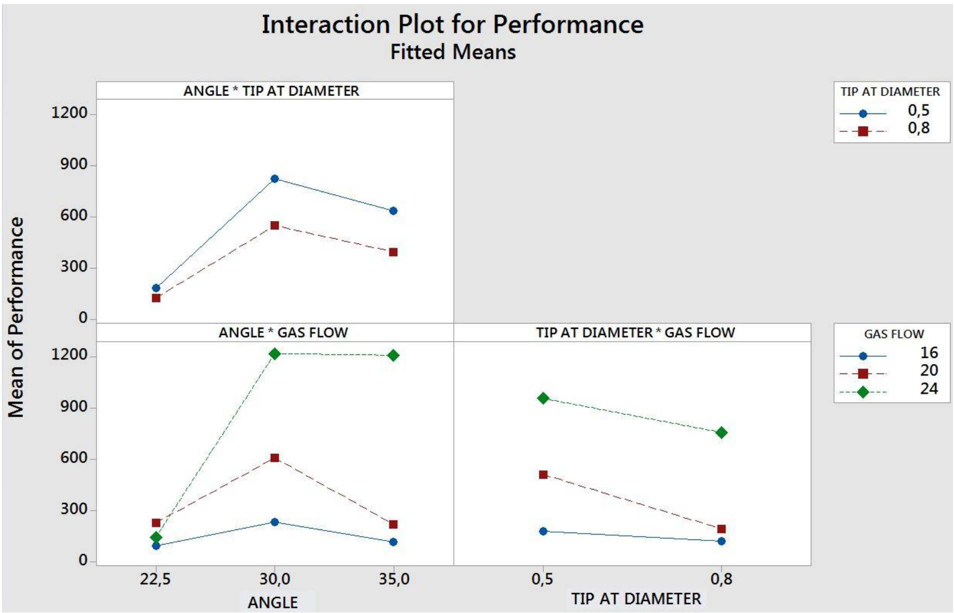


Figure 9. Interaction of Main effects Plot (from the authors, 2017)

Based on the results obtained through the tests performed, some points became evident, for example, that the diameter at tip of the electrode does not have any influence on the useful life of the tungsten electrode, however, as indicated by different manufacturers, its existence is essential, especially so that there is no inclusion of tungsten during the formation of the strands resulting from the weakening of the electrode tip during the process.

Gas flow showed to be very relevant during the execution of the process. This importance is evidenced by the results obtained during the welding with low flow (16 l / min), since the time of use of each edging until the limit of the useful life was reached was extremely low. Thus, it is concluded that in addition to the protection of the melting pool (main function of the inert gas during welding) the gas also has a relevant participation in the performance results in the life of the electrode.

At the sharpening angle, a great change in the electrode performance was observed when it changed from 22.5 to 30 degrees and already a reduction in this performance with the angle of 35 degrees.

In the interaction between the analyzed variables, it was verified that the combination between the ideal flow rate and the correct grinding angle is able to provide good performance values when evaluated over the useful life aspect. Thus, this combination is able to provide a good reduction in the costs of operational inputs and also reduce the time spent with machine preparation and sharpening of the electrodes.

6. CONCLUSIONS

Different researchers already report that the shield welding gas are of great importance in the protection of the deposited material and also against the atmospheric contamination during the welding process. The results presented can be used as guidelines for higher quality and efficiency in welding practices. The tests performed showed significant results, reaffirming this already consolidated importance, considering that the best results were obtained with the gas flow between 24 and 30 l/min.

Confirming also with the results already reported by Dobránszky et al, the useful life is directly linked with the correct choice of the electrode, such as diameter, alloy type and alloy quantity of the electrode, arc length, shielding gas velocity and flow pattern and form of the electrode tip.

The great differential of the results was the full visualization of the impact that the combination of the gas flow with the grinding angle provided to the useful life of the tungsten electrode in the cladding process, considering that the penetration of welding in this process is not a functional requirement of the final product.

As a final conclusion of the studies executed, it is suggested to use the following parameters for the execution of clad welding by automatic TIG process:

- Gas Flow: 24 l/min
- Diameter at tip: 0,5mm
- Sharpening angle: 30 degrees

It is extremely important to point out that gas flow values must be observed in the values that were established as minimum and maximum range during the qualification of the procedure.

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