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# Welding Productivity Indicators: A critical analysis.

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**Abstract:** *Welding is one of the main activities of the construction of process plants and one observes the use of several indicators in the monitoring of its productivity. In this article, the behavior of the welding productivity of ASTM A-36 steel are evaluated with the Cored Wire (FCAW) process using the E71T-1C/M electrode and two shielding gases: ArC-25 (75% Argon and 25% $CO_2$) and ArC-40 (60% Argon and 40% $CO_2$). The specimens were welded with procedures that met the requirements of AWS D1.1 [37] and the welding consumables used were approved in the qualification tests of AWS A5.36M / A5.36 (2012). In this evaluation, the following indicators were employed: Melt-off Rate, Deposition Rate, Operating Factor, Deposition Efficiency and Welding Productivity. In view of the productivity being a random process, the Monte Carlo Method was used with the software @RISK 7.5, for evaluation of its behavior. The results obtained evidenced that when the Melt-off Rate, Deposition Rate and Deposition Efficiency indicators are used, the welds produced with the gas ArC-25 present a higher productivity. However, when the Operating Factor and the Welding Productivity is used, the joints welded with gas ArC-40 present better results.*

***Keywords:****Welding Productivity, Operating Factor, Melt-off Rate, Deposition Rate, Deposition Efficiency, Monte Carlo Simulation.*

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## I. Introduction

In the construction industry, the performance of the production process involving workforce, materials and equipment is called Productivity [1]. In this industry, the most used methodology to assess the productivity may be expressed by Equation 1, which is widely mentioned in the literature. [2]-[6]

$$Productivy = \frac{Man-hours\ (MH)}{Output\ \ quantity} \tag{1}$$

In the construction of industrial plants, welding is the most important process and is observed in the literature, that the methodologies to evaluate the performance of this activity are guided by distinct trends. Such methodologies may be grouped in two groups, namely: 1 – Methods that take the filler metal deposition process into consideration during welding; 2 – Methods that encompass the executive welding procedure, with all its activities, among which the following may be mentioned: filler metal deposition, interpass cleaning and definition of interpass temperature.

The methods that take into consideration the filler metal deposition process during the welding are based on the evaluation of the open arc time, period in which there is fusion of the filler metal. In such methods, the performance is defined by the open arc time and or the quantity of filler metalmelted during welding. Among such methods, the most mentioned in the bibliography for welding performance evaluation are the following: Filler metalMR, Filler metalDR, Deposition Efficiency and Operation Factor. [7]-[25].

The methodologies of evaluation of welding productivity that taking into consideration all activities comprising the executive procedure in welding are widely used in the industry. In this case, the welding productivity indicators are in line with the concept of productivity expressed in Equation (1). [26]-[35]. Among such indicators, some differences are noticed, among which the following are highlighted: Quantity of Man-Hours (MH)consumed in welding; Activities comprising the welding procedure; Incorporation in the indicator of the productive or unproductive times; Quantity of weld produced. Regarding the quantity of Man-Hours, it is observed that there is not a single standard; only welders, welders and helpers, welders - helpers - supervisors and other professionals may be accounted for. Concerning the activities comprising the welding procedure, only those involved in the procedure are considered, for example, filler metal deposition with open arc, interpass cleaning and definition of pre-heating and interpass temperatures. On the other side, the time spent in support activities may also be recorded, among which torch positioning and ground clamp and welding machines regulation. Likewise, there may be also two types of indicators: the one that only takes into consideration the time consumed in productive activities, in which the worker is performing an activity of the welding procedure, which is called process productivity; global productivity in which one consider all times, productive and unproductive, spent in the welding procedure. The unproductive times are resulted of any event, where welding, for some reason, is stopped. [26], [27], [28], [29], [35]. The most used types of indicators in this definition are the following: MH/kg, MH/$cm^3$ and welded joints/day [26]-[35].MH/kg indicator represents the quantity in kg produced by the quantity of men hour of the team engaged in the welding. In case of the MH/ $cm^3$ indicator, it represents a weld volume in $cm^3$produced by the quantity of Man-Hoursof the team engaged in the welding. Both for the MH/kg and the MH/ $cm^3$ indicator, the quantity of Man-Hours involved in the welding may account only the welder, welder + helper and welder + helper + supervisor in the first hierarchical ranking level. However, in pipelines welding [31], [35] the joints/day indicator is observed, which expresses the quantities of joints produced in a work day by a certain welding team. It is highlighted that such indicators are used, both in the definition of the global productivity and in the process productivity.

Analysing the methodologies described herein, which one would be the most appropriate for the productivity evaluation of a welding process and/or procedure? So, in this paper, one carries out an evaluation of the behavior of productivity of the ASTM A-36 steel welding with E71T-1C/M cored wire using as shielding gas the mixture ArC-25 (75% Argon and 25% CO2) and other procedure in which the shielding gas used is the mixture ArC-40 (60% Argon and 40% CO2), by utilizing each of the welding productivity indicator discussed previously. On the other side, taking into account that the productivity behavior is a random process, the Monte Carlo Method was used as evaluation tool. [26], [28], [29], [35].

## II. Experimental Procedure

### 2.1Making of specimen

The welding of the specimen was performed with the Flux-Cored Arc Welding (FCAW) process using two shielding gases: ArC-25 (75% Argon and 25% $CO_2$) and ArC-40 (60% Argon and 40% $CO_2$*)*. The base metal used is ASTM A-36 steel and the filler metal is the E71T-1C/M wire. The weld metal of the welded joints produced with the two gases were submitted to the tests provided in the AWS standard homologation process. A5.36M/A5.36 [36], which presented satisfactory results. The chemical composition and the mechanical properties of the welding metals produced are presented in Tables 1, 2 and 3.

**Table 1. Chemical Composition of Weld Metal obtained with gas ArC-25 and ArC-40.**

| Chemical | AWS Maximum Values | Weld Metal ArC-25 | Weld Metal |
|---|---|---|---|
| C | 0,12 | 0,03 | 0,036 |
| Mn | 1,60 | 1,14 | 1,20 |
| Si | 0,90 | 0,29 | 0,329 |
| P | 0,030 | 0,009 | 0,0086 |
| S | 0,030 | 0,003 | 0,0029 |
| Ni | 0,50 | 0,34 | 0,267 |

**Table 2. Tensile test results of weld metal obtained in welding with the gas ArC-25 and ArC-40**

| Tensile Test Properties | AWS Maximum Values | ArC-25 Weld metal | ArC-40 Weld metal |
|---|---|---|---|
| Tensile Strength (MPa) | 490 a 620 | 552 | 575 |
| Yield Strength (MPa) | 390 (Minimum) | 449 | 520 |
| Elongation (%) | 20,0 (Minimum) | 27,0 | 28,2 |

**Table 3. Results of impact test of weld metal obtained in welding with gas ArC-25 and ArC-40**

| | AWS Requirements | ArC-25 Weld Metal | ArC-40 Weld Metal |
|---|---|---|---|
| **Average of Impact Energy (J)** | 27 minimum | 163 | 149 |
| **Temperature (ºC)** | - 20 | - 20 | - 20 |

The dimensions of the specimen are the following: plate width: 80 mm; Length: 150 mm; Thickness: 9.52 mm; Bezel angle: 22.5º ±2º; Root openness: 3 mm; Nose: 0 mm; Metallic backing (Thickness - 6.35 mm, Material: ASTM A36; Length: 180 mm; Width: 40 mm).

For data collection for definition of productivity with the indicators studied herein, thirty (30) butt joints were welded for each of the shielding gases in three different test positions according to AWS D1.1 [37] standard, which are: 2G (horizontal position), 3G (uphill progressionvertical position) and 4G (overhead position). Such test positions, according to this standard, qualify the welders to all positions likely to happen during a work. In order to reproduce the conditions of a welding performed in the field, the order of welding of the specimen were randomly selected via drawing.

In the welding of such specimen, (05) different welders were used, which were qualified according to AWS D1.1 [37] standard. Data collection of the electric variables in the specimen welding with the shielding gases ArC-25 and ArC-40 was performed using the Portable Data Acquisition System of the company IMC, called SAP-1 and registered the following data: open arc time, average welding current, average arc voltage, wire power speed and quantity of wire consumed. The main statistics of such variables are presented in Table 4.

**Table 4.Statistics of variables electric of welding of specimens using the shielding gases ArC-40 and ArC-25.**

| Shielding gas | ArC-40 | ArC-25 |
|---|---|---|
| **Welding Current Mean(A)** | 187,09 | 174,32 |
| **Standard Deviation of Welding** | 14,12 | 11,76 |
| **Coefficient of Variation of Welding** | 0,08 | 0,07 |
| **Welding Voltage Mean (V)** | 23,23 | 22,75 |
| **Standard Deviation of Welding** | 0,77 | 0,79 |
| **Coefficient of Variation** | 0,03 | 0,03 |

### 2.2. Methodology for Evaluation of the Productivity Focused on Filler Metal Deposition

The indicators used in this work are: Melt-off Rate (MR) of the filler metal, Deposition Rate (DR) of the filler metal, Deposition Efficiency (DE) and OperatingFactor (OF). The definition of such indicators is obtained through the equations (2), (3), (4) and (5). For the definition of the indicators listed above, the parameters monitored in each specimen are the following: mass of specimen before and after welding – grams (g); open arc time – seconds (s); length of wire used – meters (m); wire-feed speed – meters per minute (m/min); total execution time of each weld bead – seconds (s); length of each bead – millimeters (mm). The specimen masses were measured before and after the welding, with weighing scale with measurement capacity of ±0.1 gram. The final mass of the specimen was defined after they reached room temperature. Through the use of the Portable Data Acquisition System of the company IMC, called SAP-1 the following data were registered: open arc time, average welding current, average electric arc voltage, wire-feed speed and quantity of wire consumed. The MR is defined as quantity of filler metal, electrode, wire or rod, melted in the time unit and expressed in the International System (SI) units in kg/h. The welding time taken into consideration is the **open arc time.** In this case, the definition of the quantity of melted metal is obtained by weighing the filler metal, before and after the welding.

$$MR = \frac{\text{Quantity of filler metal melted } (kg)}{hour\ (h)} \tag{2}$$

The Deposition Rate (DR) of filler metal is the quantity of filler metal, which has been effectively deposited during the welding in the time unit and is expressed in SI units in kg/h. The welding time taken into consideration is the **open arc time.** It is worth pointing out that, in this case, the quantity of the metal deposited is defined by the weighing after the filler metal is added to the welded joint.

$$DR = \frac{Quantity\ \ of\ deposited\ \ metal\ (kg)}{hour\ (h)} \tag{3}$$

The Deposition Efficiency (DE)expresses the comparison between the quantity of meltedfiller metal, electrode, rod or wide, and the deposited metal in the welded joint and is expressed in %. The welding time considered is the **open arc time.**

$$DE\ (\%) = \frac{Quantity\ \ of\ deposited\ \ metal}{\text{Quantity of filler metal melted}}\, x\ 100 \qquad (4)$$

The OperatingFactor (OF) comprises the relation between the open arc time and the welding total time, considering the open and close arc times. The unit used for this indicator is %, which means the percentage of open arc time during thewelding.

$$OF\ (\%) = \frac{open\ \ arc\ \ time}{Twelding\ \ total\ \ time}\, x\ 100 \qquad (5)$$

### 2.3. Methodology for Evaluation of Welding Productivity Focused in the Activities comprising the Welding Procedure

Before the welding of the specimen, the length of the weld bead, the bezel angle and the root opening through the welding gauge were measured. The specimen used fixed backing of the metallic type, not being necessary to perform the counter weld pass. The total execution time of the specimen was obtained, adopting in the beginning, the order for the welder to start the welding, once the joint is positioned. After the performance of each weld bead, the removal of the slag was performed and then a visual inspection of weld, to detect any defect that should be removed. Before the welding of the following bead, it was verified that the specimen temperature with thermal pencil is 152ºC and once the temperature was below, the continuity of the welding was enabled. In the definition of the total time consumed in the welding, the following times are accounted: welding time with open arc, cleaning time between passes and time for the definition of interpass temperature. It has considered that the time consumed in the definition of the interpasstemperature was negligible and the zero value was assigned to it, which may not take place in other experimental conditions. The total execution time of each weld bead started to be accounted in the moment the welder was ready to start the process and finished after the end of the interpasscleaning. The measurement of such times was made with Casio's manual stopwatch. It is also pointed out that in this analysis the unproductive times are not taken into consideration, in which no activity related to the welding is being performed.   The productivity definition model used in this experiment is defined in the Equation (6):

$$\boldsymbol{Welding\ Productivity\ (WP)} = \frac{\boldsymbol{V}}{(\boldsymbol{Ta}.\boldsymbol{M})+(\boldsymbol{Tc}.\boldsymbol{M})+(\boldsymbol{Tt}.\boldsymbol{H})} \qquad (6)$$

Where V= Welding volume in $cm^3$, Ta = Open arc time in hours; Tc = Interpass cleaning Time in hours; Tt= Time spent in the definition of the pre-heating temperature and interpass in hours; M = quantity of Man-Hours used in the activity. In this article the variable H corresponds to 1 welder and the times measured for Tt were considered negligible and the value of zero was assigned to them. Likewise, the volume of weld V was maintained for all specimen. In order to facilitate the results analysis, the use of the indicator $cm^3$/MH was chosen instead of MH/$cm^3$, in view of the latter representing the decreasing function, that is, the higher the value, the lower the productivity. On the other side, the curve represented by the $cm^3$/MH indicator is an increasing function, that is, the highest value indicates the higher productivity.

### 2.4. Data Processing Via Monte Carlo Simulation

After the welding of the specimens the data collected were organized in tables and proceeding to the performance of simulation through the Monte Carlo method, which comprises the generation of virtual data, pseudo-random numbers, from a sample of real data. In this work, the software @RISK [38] was used, ordered in the following steps: 1 - Organize the data collected as a table; 2 - Execute the adherence test of the possible probability distribution functions to meet the significance level of 95% in each sample used in the simulation; 3– Choose the most appropriate generator function by performing the test of adherence of the possible probability distribution functions, to meet the 95% significance level in each sample used in the simulations; 4 - Simulate with the Monte Carlo Method the data with 5000 iterations; 4 - Verify whether the number of iterations is sufficient and if not successful, the number of iterations shall be increased or a new generator function shall be adopted; 5 - Elaborate the Cumulative DistributionFunction (CDF) curves through which the analyses will be performed. It is worth pointing out that for the determination of the CDF curve for the MR, DR, DEand OF step 2 comprises the determination of only one generator function for the indicator that is being evaluated, which corresponds to the one which Probability Density Function (PDF) has more adherence to the sample data. However, for the WP indicator expressed in the Equation (6), PDF generated via Monte Carlo simulation for this variable involves the definition of the generating functions defined to Ta and Tc, with V and H being constant.

In case of WP it is possible to perform a sensitivity analysis, through a Tornado type chart, in which the impact of a certain variable is evaluated regarding the main being object of analysis [26], [39], [40], [28], [29], [41], [38], [35]. This tool is made available in the software @RISK version 7.5. This analysis is intended to verify the influence of the times of interpass cleaning and the open arc times in the average of WP, using the types of shielding gases, ArC-25 and ArC-40.

## III. Results and Discussion

In this section, the results of the CD curves and the main statistic obtained in the experimented performed are presented. On the other side, in the cm3/MH productivity indicator evaluation, for the analysis of the impact of each activity, which comprise the welding procedures used, the tornado chart is also presented.
In Figure 1 it is observed regarding the MR, the results obtained with the use of the gas ArC-40 are higher than the ones obtained with ArC-25. This result was expected since the fusion of the electrode is proportional to the current intensity, as widely known in the literature. Therefore, the higher the amperage, the higher the MR obtained and as seen on Table 4, the current registered in the welding with gas ArC-40 is higher than the one verified with gas ArC-25.

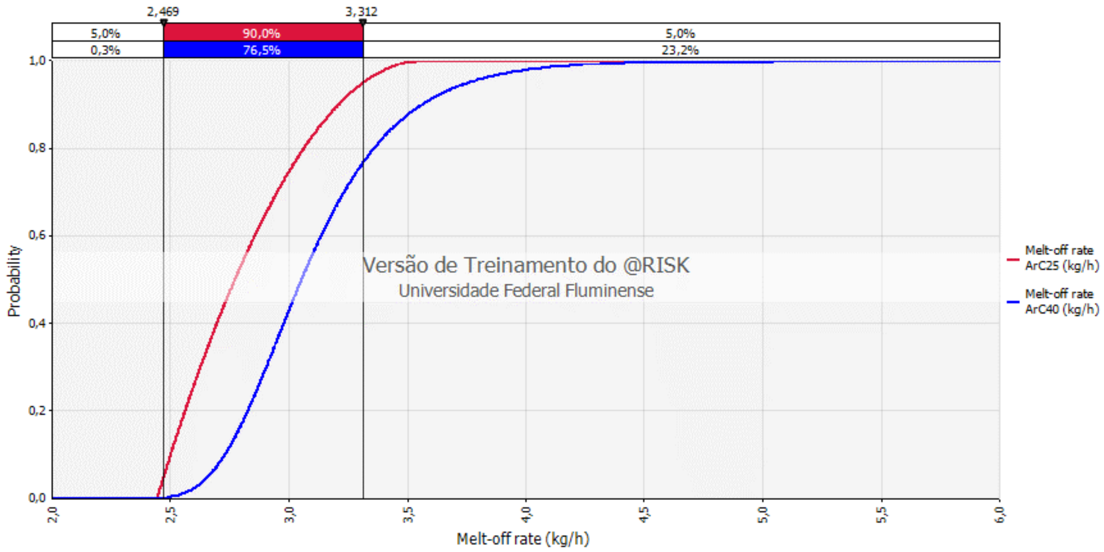


**Figure1.Comparison between the Melt- off Rate of E71T-1 c/M Electrode on the welding with ArC-25 gas and ArC-40.**

The OF represents the percentage of the open arc time regarding the total welding time. Therefore, the events that decrease the open arc time have impact on the reduction of such indicator. Figure 2 reveals an occurrence probability, slightly higher in the welding with gas ArC-25 in comparison with the welds performed with gas ArC-40. This not only happens for too high values of the OF in which the probability of occurrence is low. In this case, there were two events that contributed the most for the reduction of the open arc time in the welding with gas ArC40: stability of the electric arc and time of interpass cleaning. In this regard, it is observed on Table 4 that the electric arc stability in welding with gas ArC-25 is slightly higher than the one produced with gas ArC-40. The coefficient of variation of the current for the arc produced with gas ArC-25 is 0.07, while with ArC-40 is 0.08. As aforementioned, the welding current is related to the filler metal deposition and directly influences the quality of the weld bead produced. In this regard, it was observed that welding with gas ArC-40 presented a higher quantity of splatter and higher incidence of superficial discontinuities, which had to be removed during the welding. Therefore, such factors entailed a higher consumption of time of such activities with the subsequent reduction of the percentage of open arc time regarding the total welding time. On the other side, it was observed that the slag produced in the welding with the gas ArC-40 had higher adherence than the one obtained with gas ArC-25. This fact had as consequence an increase of the cleaning time between pass in the welding performed with ArC-40, which also contributed to the reduction of the percentage of open arc time during the welding with this gas.

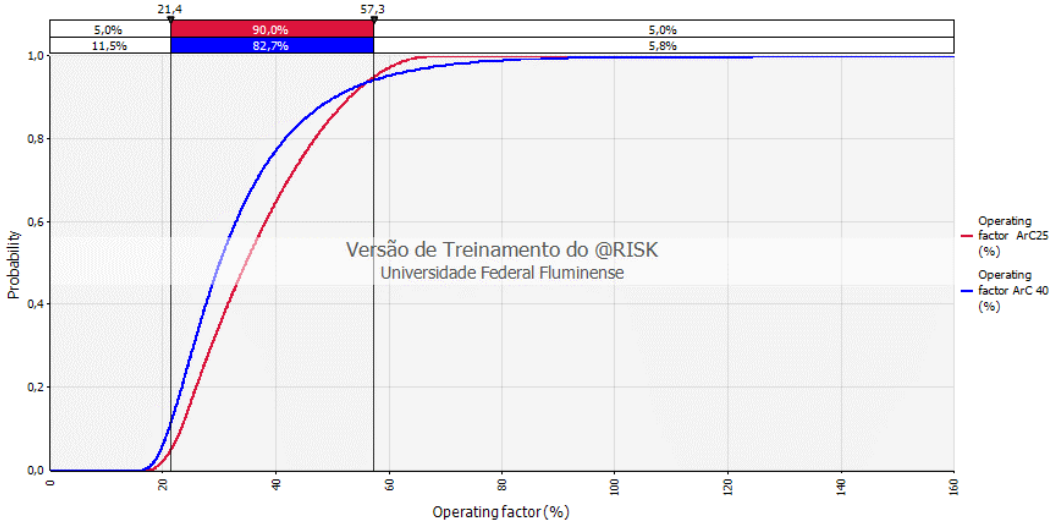


**Figure 2. Comparison between the Operating Factor of E71T-1 c/M Electrode on the welding with ArC-25 gas and ArC-40.**

Figures 3 and 4 respectively present the DR and the DEfor the welding performed with gases ArC-25 and ArC-40. The DR represents the quantity of filler metal, which was effectively deposited, during the open arc time in the welding. Therefore, the behavior of this indicator is related to the amperage, as the Melt-off Rate (MR) of the electrode previously discussed and presented in Figure 1. On the other side, the highest adherence of the slag observed in the welding with ArC-40, could have as consequence a stronger adherence in the quantity of metal deposited due to the removal of material during the interpass cleaning. Therefore, if the impact is an event of this nature was significant in comparison with the results obtained in the welding of the ArC-25 gas, that would be evidenced in the DEresults presented in Figure 4, which did not occur. In this regard, by observing Figures 3 and 4, it is noticed that the probability of occurrence of a better performance is obtained with the use of the gas ArC-40.

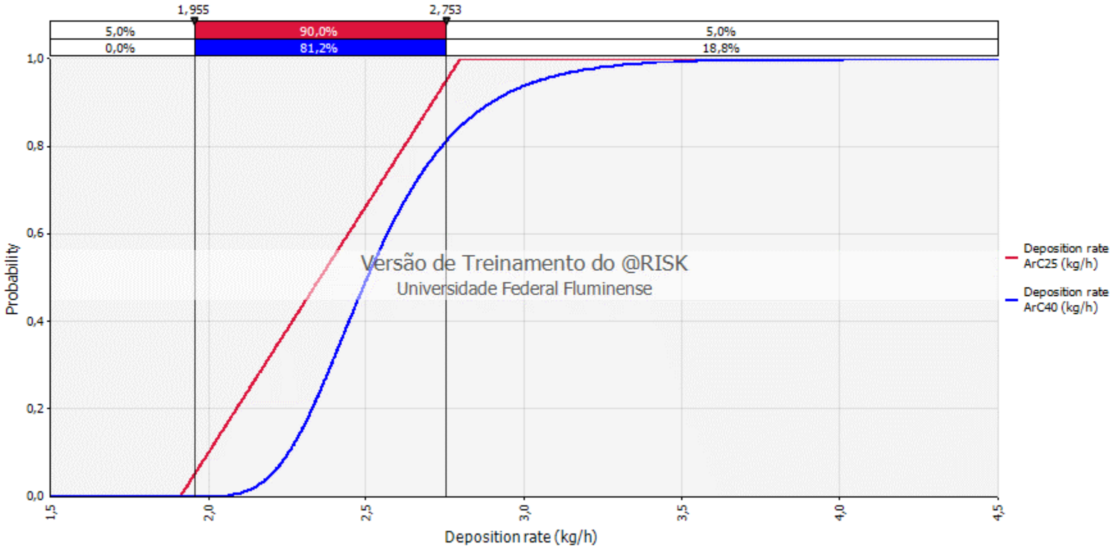


**Figure 3. Comparison between the Deposition Rate of E71T-1 c/M Electrode on the welding with ArC-25 gas and ArC-40.**

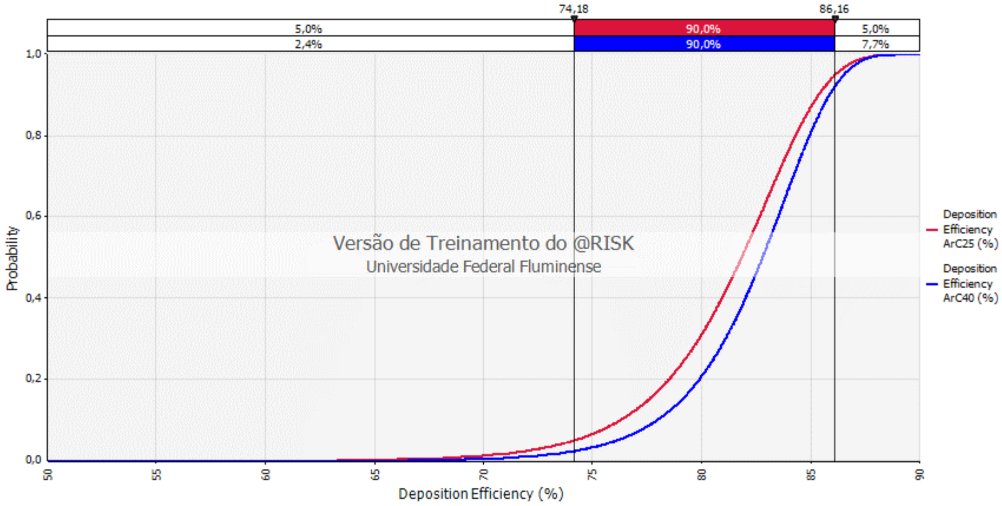


**Figure 4. Comparison between the Deposition Efficiency of E71T-1 c/M Electrode on the welding with ArC-25 gas and ArC-40.**

Figure 5 presents the productivity expressed in cm3/MH which represents the volume of deposited welding by the quantity of MH consumed. It is worth pointing out that only a welder was taken into account per specimen, however, in the industrial activity it is a common practice to account in the quantity of MH consumed in the welding, the use of helpers and first level supervisors. [26]-[35]. Likewise, in the definition of productivity, activities comprising the welding procedures were taken into consideration, namely: filler metal deposition, definition of pre-heating and interpass temperature. The times involved in such activities are considered, from the statistic point of view, as mutually exclusive, that is, they cannot take place at the same time. The times consumed in the measure of pre-heating and interpass temperature were insignificant and, therefore, they are not included in the calculation of productivity. It shall be registered that in welding of metallic alloys that require higher pre-heating and interpass temperature and stricter temperature control, probably such times would not be insignificant, but those shall be accounted case by case depending of the type of base metal. Therefore, the times consumed in the filler metal deposition were registered, corresponding to the open arc time and interpass cleaning. In Figure 5 it is noticed that the probability of productivity in the welding with the shielding gas Arc – 40 is higher than the one obtained with ArC-25 is lower than 20% and takes place only for productivity levels around 160 $cm^3$/Hh. This fact presents a trend opposed to the one verified in the definition of MR, Figure 1, DR, Figure 3 and DE, Figure 4. On the other side, this result is more aligned with the results of the OF presented in Figure 2 in which a value obtainment trend is observed, slightly higher in the welding with gas ArC-25. This may be explained by the fact that in the indicators, OF andWP, the open arc times and interpass cleaning are taken into consideration, which does not occur in the others.

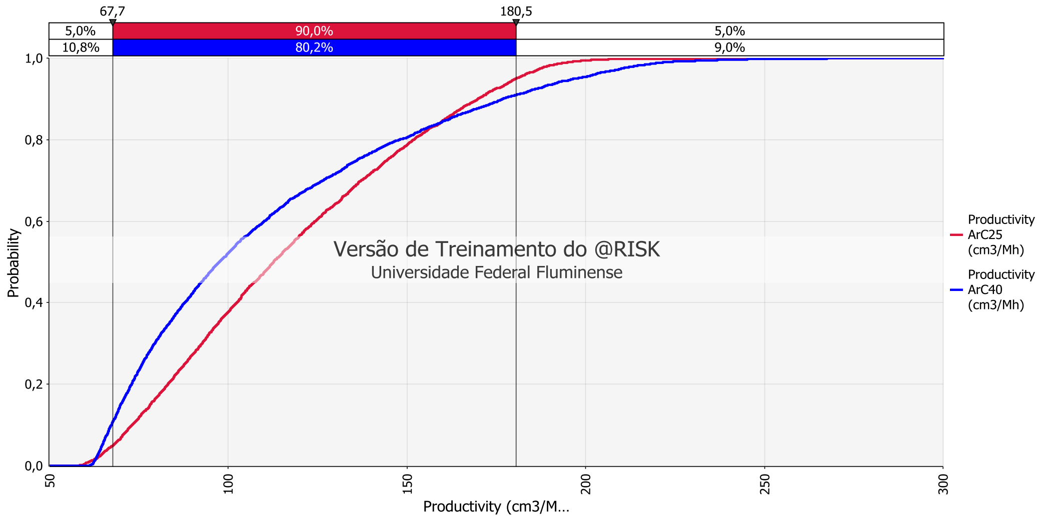


**Figure 5.Comparison between the Welding Productivity in $cm^3$/MH of E71T-1 c/M Electrode on the welding with ArC-25 gas and ArC-40.**

Figures 6 and 7 presents, respectively, the impact of the open arc times and interpass cleaning in the welding with gases ArC-25 and ArC-40. The charts presented in these figures are the Tornado type which enables to evaluate the impact each **"recorded time"** variable in the average of productivity, only taking into consideration the possible variations of each of them, keeping the other constant. As observed in Figure 6, the average productivity of 117.45 $cm^3$/Hh, may vary from 109.46 (-6.8%) to 126.77cm3/MH (7.9%), due to the values of the open arc times likely to occur during the welding. Regarding the impact on the interpass cleaning times in the average of productivity, it is observed in Figure 6 the values of 67.207cm3/MH and 180.40 cm3/Hh, which correspond, respectively, to a variation of -42.8% to 53.6% in relation to the average.

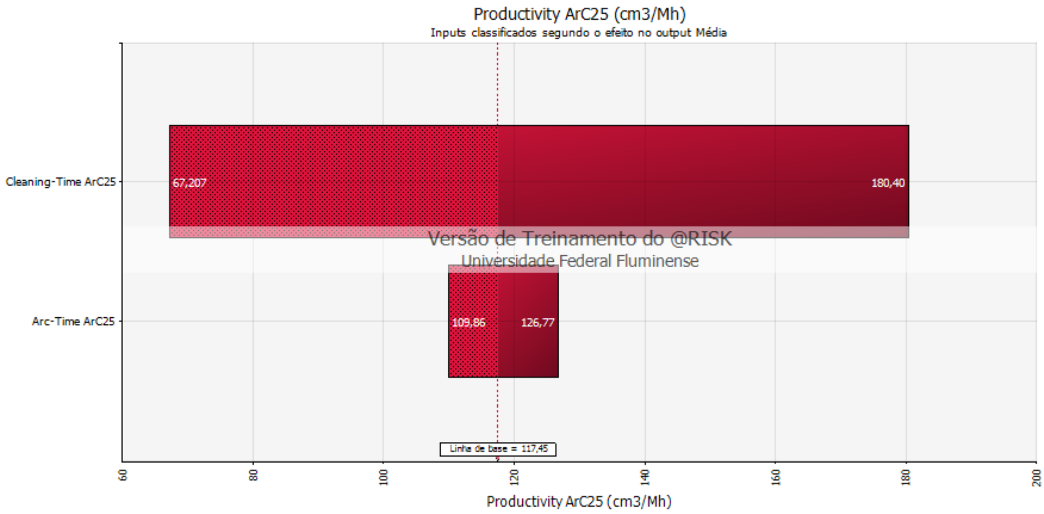


**Figure 6.Impact of arc time and cleaning time interpass in welding with electrode E71T-1 c/M with the gas ArC-25.**

In Figure 7 it is observed that the average of productivity of 110.64cm3/MHmay vary from 104.72 (-5.4%) to 122.65cm3/MH (10.9%), due to the values of the open arc values likely to occur during the welding with gas ArC-40. Regarding the impact of the interpass cleaning time in the productivity average, it is observed in Figure 7 the values of 64.815cm3/MHand 199.15 $cm^3$/Hh, which correspond, respectively, to a variation of -41.4% to 80.0% in relation to the average. Therefore, it is verified both in the welding procedure using the gas ArC-25 and the one using ArC-40, that the impact of the interpass cleaning times is much more significant thanthat related to the open arc times, which explains the higher probability of occurrence of productivity values higher than with the use of ArC-25. It is also pointed out that the procedure using the gas ArC-40, in which the probability of occurrence of values significantly higher than the average is way higher than the ones observed with gas ArC-25, indicating that interpass cleaning time is the activity most critical when choosing the gas ArC-40.

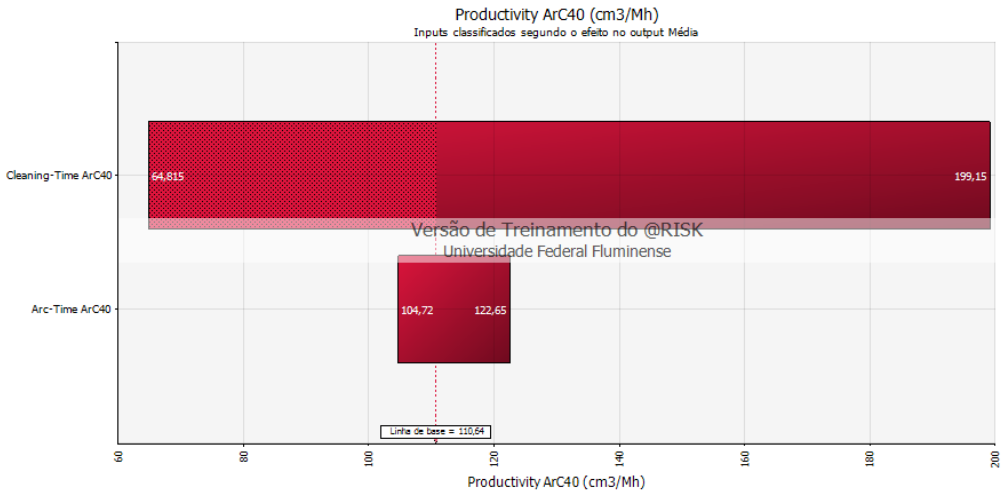


**Figure 7. Impact of arc time and cleaning time interpass in welding with electrode E71T-1 c/M with the gas ArC-40.**

Table 5 presents the main statistics of the productivity indicators of the welds produced with the procedures using the shielding gases ArC-25 and ArC-40. By observing the data on this table, it is verified that the MR, DR and DE, indicate that the welding productivity is higher in the welding procedure with ArC-40. Likewise, it is observed that the values obtained from the variation coefficient, which indicates the dispersion of the curves of such indicators around the average, are 0.11 and lower. Such indicators are defined taking into consideration the open arc times during the welding. Therefore, such behavior may be explained by the low impact of the open arc time in the average of such indicators, as shown by Figures 6 and 7. However, when analysing the results of the OF and WP, the behavior is the opposite. In this case, the results of the welding performed with ArC-25 indicate that the productivity is higher than the one obtained using gas ArC-40. On the other side, the results obtained by the variation coefficients related to the OFare 0.31 in the welds performed with ArC-25 and 0.40 for ArC-40. In case ofWP the variation coefficients present a similar behavior, recording 0.30 for welds produced with ArC-25 and 0.38 for ArC-40. Such high dispersion values recorded in those two indicators may be explained by the significant impact on the average of them of the interpass cleaning times, as in both cases it is noticeable, as shown in Figures 6 and 7. In the calculation of the OF such times are taken into consideration in the total welding time and in the WP in the interpass cleaning times.
Figure 7 shows that the impact of the welding cleaning times with gas ArC-40 is higher than the one performed with ArC-25, which explains the higher dispersion around the average recorded by ArC-40.

**Table 5. Statistics of productivity indicators in the Welds Produced with the gas ArC-25 and ArC-40.**

| **Statistics** | **MR (kg/h)** | | **OF (%)** | | **DE (%)** | | **WP ($Cm^3$/MH)** | | **DR (kg/h)** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ArC25 | ArC40 | ArC25 | ArC40 | ArC25 | ArC40 | ArC25 | ArC40 | ArC25 | ArC40 |
| **Mean** | 2,82 | 3,11 | 36,43 | 33,49 | 81,23 | 82,27 | 117,45 | 110,64 | 2,35 | 2,55 |
| **Standard Deviation** | 0,26 | 0,35 | 11,22 | 13,28 | 3,78 | 3,29 | 35,62 | 42,41 | 0,26 | 0,27 |
| **Coefficient of variation** (*Mean/Standard Deviation*) | 0,09 | 0,11 | 0,31 | 0,40 | 0,05 | 0,04 | 0,30 | 0,38 | 0,11 | 0,10 |

The obtained results reveal that, depending on the indicator choice, the conclusion regarding the productivity in welding may be different. Therefore, when the MR, DR and DE indicators are adopted, the welding with ArC-40 presents a better productivity. On the other side, when using the OF and Welding Productivity, ArC-25 presents a performance higher than ArC-40. As previously described, this difference is related to the fact that the MR, DR and DE, the welding performance is only related to the filler metal deposition during the open arc time. In this case, the times consumed by other activities, such as interpass cleaning, are not taken into consideration. However, when regarding OF and WPindicators, in which interpass cleaning times are taken into consideration, their impact on the final resultis significant, as shown by Figures 6 and 7. It is worth pointing out that in case of, although the indicator focus is the open arc time, the calculation of this indicator relates the open arc time with the welding total time. Among the indicators studied, it seems that WP is the most indicated for industrial purposes, as it quantifies both the weld volume produced and the quantity of Man-Hours spent in the activity, and its format is aligned with the productivity concept most used in the industry. Another relevant aspect is that the form of building this indicator allows to evaluate the impact of each activity in the final result, as in this case the influence of the activities performed in a welding procedure may be evaluated to decide more precisely, which actions may be performed for productivity improvement. It is also worth pointing out that in this case we refer to the process productivity, previously defined, in which only productive times are taken into consideration, but in the industry, for terms and budget estimate purposes, the global productivity indicator is usually used, in which one considers the productive and unproductive times.

## IV. Conclusion

The results obtained revealed that the Melt-off Rate (MR), Deposition Rate (DR) and Deposition Efficiency (DE) indicators may indicate a trend of the welding productivity behavior different from the Operating Factor (OF) and Welding Productivity (WP). Therefore, when the MR, DR and DE indicators are adopted, the welding procedure using gas ArC-40 presents a higher productivity trend than the welding performed with ArC-25. However, by employing the OF and Welding Productivity indicators, the welding performed with ArC-25 present a higher productivity.

One verifies that the dispersion around the average of the Operating Factor (OF) and the Welding Productivity (WP) are above the ones recorded in the Melt-off Rate (MR), Deposition Rate (DR) and Deposition Efficiency (DE), presenting higher uncertainties in its definition.

The equation of calculation of the Welding Productivity (WP) indicator enables to evaluate the influence of each activity in the final result. In this regard, it is possible to direct the actions that may contribute for the improvement of the productivity in more critical activities, which is not possible when one uses others indicators.

The result analysis showed that Monte Carlo simulation is a powerful tool in the development of studies about welding productivity. Likewise, in the study of productivity models using this technique, it is possible to consider all the activities of the production process under analysis. Thereby, it is feasible to evaluate the impact of each activity on the productivity of the process as a whole.

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