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Characterization of the Parameters in FCAW Welding Process in Alloy Steel Using Statistics

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***Abstract*—The FCAW (Flux Cored Arc Welding) have presented a continuous development because they have high productivity, low cost and adequate for automated processes. Furthermore, these processes present high deposition rate and high quality welding. In this work, welds that FCAW process were done out in flat position in plates of alloy steel 4340 with pre-heating, normal and pos-heating. In order to make a comparative evaluation concerning to metallurgical properties, penetration, HAZ and dilution. Used a statistical tool based on technical analysis and design of experiments, DOE, from the Minitab software. For these analyses, were varied the current, voltage, and welding speed. As a result, observed that the welds had different characteristics in relation to the metallurgical properties and performance, but they present good quality, satisfactory mechanical strength and more refined microstructure in plates with pre-heating.**

***Index Terms*— DOE, FCAW, quality, microstructure.**

I. INTRODUCTION

In industrial manufacturing, the main welding processes GMAW (Gas Metal Arc Welding) also called MIG/ MAG and FCAW (Flux Cored Arc Welding) due to its many advantages, such as: used in welding all commercial metals and alloys special, high deposition rates, continuous feeding of the consumable wire and easy automation. Some characteristics such high productivity, good flexibility and ease of operation make them highly competitive GMAW and FCAW processes [1].

The use of FCAW process has happened due to the reduction in the use of shielded electrode technique [2]. The FCAW have presented a continuous development because they have proven to be flexible, low cost and adequate for mechanical processes. Furthermore, these processes present high productivity, high deposition rate and high quality welding [2]. The FCAW and GMAW processes are widely applied in the oil industry. Both processes are apply to several types of steel, like low carbon steel, stainless, among others [3]. However, studies related to their microstructure and mechanical properties need more studies.

According Araujo [4], the FCAW process stands out for generating a deposited metal and weld quality with good looks, high deposition rate and even greater tolerance for the presence of contaminants that can cause the appearance of cracks.

Aiming to meet the demands for quality welding, the optimization of the variable in the welding processes is necessary: voltage, current and speed [4]. For this purpose, the use of methodologies based on the statistical analysis has become invaluable to cover the analyses of the parameter influence isolated or through interactions [5].

Studies show that the rise in welding voltage leads to a reduction of the weld bead width and the increase in welding speeds leads to a reduction of the bead width. The increase in voltage also leads to a reduction of the bead height and the increase in current rises the bead height. In terms of penetration, the most influent parameter is the current, where the higher the current, the higher the penetration [6].

The variation in temperature influences the microstructure characteristics of the material welded, and consequently can compromise mechanical properties [7]. The main areas of interest in the welded joints shown in Figure 1.

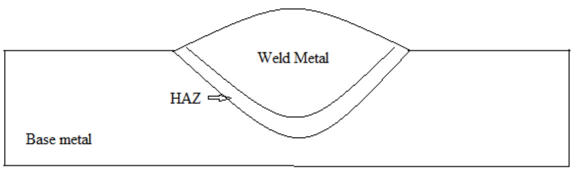

Fig 1. Welding Structure

II. OBJECTIVES

This paper studied the effects of operating parameters Current, Voltage and the use of preheating and post heating in the formation of the microstructure in the HAZ and geometric aspect measured by penetration and reinforcement.

The objectives are:

- Verify the influence of the variables on the metallurgical properties of the weld bead;
- Analyze the microstructure of steel welded using preheating and post heating;
- Verify the geometric aspect of the weld bead.

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III. Materials and Methods

To carry out the welds is mounted the set as follow Figure 2: welding machine used at work; mixture gas with 75% argon and 25% carbon dioxide, torch, support piece to be welded and a shifter car with variable speed.

Fig.2. welding tests. 1) power supply; 2) shielding gas; 3) torch; 4) specimen; 5) mechanized movement system

The specimen extracted from a steel plate with a thickness of 4340 with 5/8 "in the dimensions of 50 x 120 mm.

The material used in the research was SAE 4340. The chemical compositions are shows in Table I.

TABLE I
CHEMICAL COMPOSITION OF SAE 4340

C	Mn	Si	Cr	Ni	Mo
0.38 – 0.43	0.60 – 0.80	0.15 – 0.30	0.70 – 0.90	1.65 – 2.0	0.20 – 0.30

The welding was simple deposition, ie, a bead on the plate, using the tubular wire "in diameter 1.2 mm. The chemical compositions are shows in Table II.

TABLE II
CHEMICAL COMPOSITION OF TUBULAR WIRE

Material	C (%)	Si (%)	Mn (%)	Ni (%)	Mo (%)
Tubrod 90 MC	0.03	0.50	1.40	1.60	0.30

The flow of gas was used 12 l/min as specified by the manufacturer.

For the heat treatment (normalization, pre-heating and post-heating) was used a chamber, with temperature variation from 0 to 1300ºC. The temperature employed for pre-heating was 300°C with for 45 minute and post-heating was 550°C for 3 hours.

After welding, all the specimens subjected to metallographic preparation steps for analysis. The analysis was performed on a stereoscopic Olympus SZ 61 linked with computer; making it possible to analyze the image, shown in Figure 3. The images obtained with 6,7x magnification.

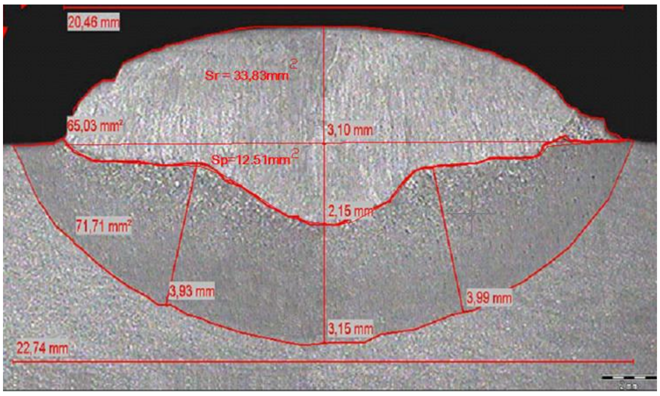

Fig. 3 - specimen photo with demarcation of areas and linear measurements

For the analysis of geometric weld bead was used penetration measures, reinforcement and dilution as Equation (1) and the quality of visual weld bead was made by observing their appearance, regularity and being attributed notes from 1 to 10.

$$D = (S_p /(S_p + S_r)) * 100\% \qquad (1)$$

Where: Sp is the area of penetration and Sr is the area of the reinforcement.

The technique used for the organization of welding parameters and analysis of the results was the factorial design with two levels (2^n), indicating the number of parameters, which for this study were three (current, pre and post-heating temperature). This design conditions generated 8 (2^3) separate experimental was repeated one more time generating a total of 16 specimens welded.

Table III shows the input variables with their respective levels and Table IV shows the experimental matrix with the information of the levels of the variables of the tests.

TABLE III
ENTRANCE VARIABLES – 16 SPECIMENS

Variables	Level (-)	Level (+)	Fixed parameters: Voltage (volts)	Fixed parameters: Speed (mm/min)	Fixed parameters: Stick-out (mm)
Current (ampere)	260	280	27.5	0.32	15
Pre heating (ºC)	0	300	27.5	0.32	15
Post heating (ºC)	0	550	27.5	0.32	15

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TABLE IV
MATRIX EXPERIMENTATION

Order of execution		Conditions	Input variables with respective conditions		
			Current (A)	Pre heating (ºC)	Post heating (ºC)
1.3	*2.4	1	-	-	-
1.7	2.1	2	-	-	+
1.8	2.2	3	-	+	-
1.1	2.6	4	-	+	+
1.2	2.5	5	+	-	-
1.4	2.3	6	+	-	+
1.5	2.8	7	+	+	-
1.6	2.7	8	+	+	+

* The first number means the replica to the second condition.

IV. RESULTS AND DISCUSSION

After the experiments and metallographic preparation of the samples were analyzes macro and micrographic in the base metal, HAZ and fusion zone. Table V shows the results of the geometrical parameters and quality for each experimental condition.

TABLE IV
IMPUT VARIABLES AND RESULTS OF THE MEANS VALUES

N	Area HAZ	Width (mm)	Penetr. (mm)	Reinf. (mm)	Sr (mm^2)	Sp (mm^2)	(D) %	Qual (1-10)
1	47.05	18.82	1.48	2.34	25.72	12.36	0.32	6.5
2	47.06	18.82	1.48	2.35	25.76	12.38	0.32	6.5
3	63.21	18.26	2.18	2.05	17.91	15.6	0.47	8.0
4	63.23	18.26	2.19	2.04	17.8	15.7	0.47	8.0
5	71.72	20.17	1.92	1.94	28.2	11.85	0.30	6.0
6	71.71	20.17	1.92	1.94	28.2	11.86	0.30	6.0
7	82.6	20.46	2.8	2.86	25.81	17.3	0.40	7.0
8	82.63	20.48	2.81	2.87	25.84	17.35	0.40	7.0

In the pre-heating conditions was noted a greater penetration and dilution.

Statistics for the analysis of the results we used the "software" Minitab, considering a significance level (α) equal to 5%, therefore the reliability of the results of 95%. Thus, values "p value" below 0.05 indicates that the effects are significant.

Table VI indicates the results of penetration, reinforcement, HAZ and dilution showing the main effects obtained for the experiment, considering the interaction of both factors. Values in bold type are those considered significant.

TABLEI VI
ESTIMATES OF THE MAIN EFFECTS

Factors	*p-value*			
	Penetration	Reinforceament	HAZ	Dilution
Current (A)	**0.002**	0.316	**0.000**	**0.017**
Pre heating (B)	**0.000**	0.173	**0.001**	**0.000**
Interaction (AB)	0.285	**0.028**	**0.03**	0.309

Results shown in Table VI confirm the presence of pre-heating to welding of the Alloy steel 4340, which is a significant factor in response Penetration, HAZ and dilution. The current had a most satisfactory factor for penetration, dilution and HAZ.

The graphs of Figures 4, 5, 6 and 7 show the main effects of factors: pre-heating current and for the responses. The figures confirm that the presence of the pre-heating increased the response values. In the last graph, Figure 7, observe that the higher current level (higher heat input) increased the reinforcement of the weld.

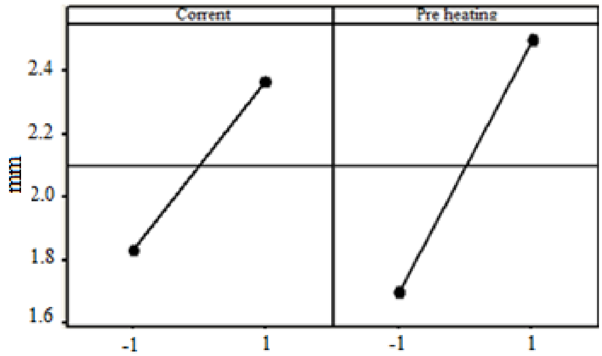

Fig 4 – Main effect on the penetration in milimeter.

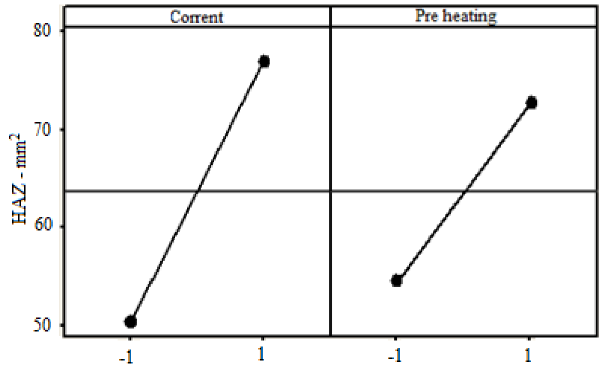

Fig. 5 – Main effect on the HAZ

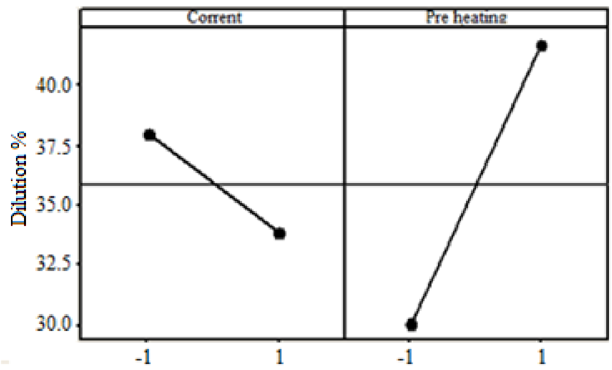

Fig 6 – Main effect on the dilution

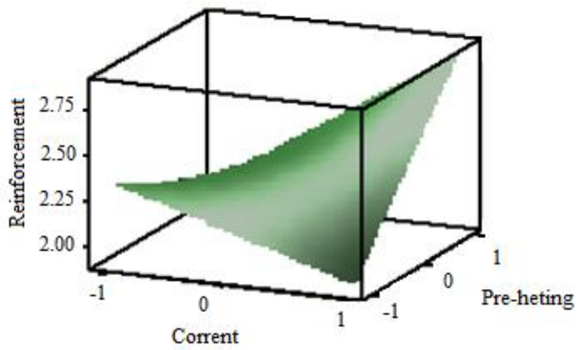

Fig. 7 - interaction current x pre heating

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In Figure 8, the micrographs obtained by the optical microscope under certain conditions of welding, specifically: Base Metal, HAZ and Weld Metal are shown. Observed changes in the microstructures only the variation of the frequency. The micrographs are on a scale of 0.02mm.

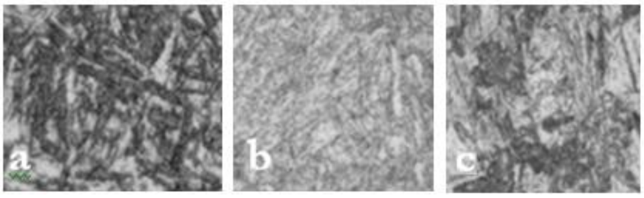

Fig. 8 - Micrographs of the center of the HAZ: (a) without pre and post-heat treatment; (b) Only pre-heating; (c) pre and post-heating.

The first welding condition without pre-heating and post-heating without heat affected zone, Figures 8a was characterized by the presence of predominantly martensitic structure and by the occurrence of acicular ferrite. It is emphasized that the analysis was conducted by comparing the results with literature [10].

The welding condition with only the heat affected zone pre-heating Figures 8b, the presence of small traces of fine martensite was observed (M), the presence of bainite (B) and ferita acicular in larger quantities (AF).

The welding condition with the presence of pre-heating and post-heating can be checked again the occurrence of martensitic structure, but more "diffuse," ie, with typical aspect of tempered martensite. There were also bainite (B), ferita of grain boundary, acicular ferrite (AF) and also the presence of perlite (darker part).

V. Conclusions

The FCAW process was observed that the welding performed showed no apparent cracks in your bead and with a good geometric aspect.

The experimental conditions in presence of preheat had a significant influence on penetration and dilution increasing their values, and also reduced the percentage of martensitic phase in the HAZ.

Another important fact the presence of the preheat increase the dilution. This occurs because the distances between the grains increase.

The micrograph shows that with pre-heating and pos-heating, the HAZ and the Weld Metal had a microstructure improved over conventional welding.

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