EVALUATION OF RESISTANCE WELDING PROCEDURES SUITABLE FOR THE SAE 1008 WIRE RODS ASSISTED BY DOE TECHNIQUE.

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Abstract. *In this paper an experimental procedure is proposed to evaluate the effect of the welding parameters on mechanical properties of carbon steel wire rods weld joints using resistance welding. Constant failure at the weld joint has been observed under mechanical descaling procedure. Based on the welding machine parameters range, tensile test, bending test and using an statistical tool of analysis this study aims to develop an optimum welding procedure that enhance the welding joint mechanical property and assure its performance under cyclical deformation and subsequent drawing needed to produce cold formed rebars.*

Keywords: *resistance welding, carbon steel, wire rod, mechanical descaling.*

1. INTRODUCTION

The resistance welding process is largely used to joint wire rods at continuous wire drawing processes, due to its stronger welding joint and because it is an easier, faster and cheaper welding process compared with arc welding. However, the weld joint remains as the most critical region. To assure the continuity of the wire rod properties at the joint, avoiding the failure under process and guarantee the productivity, it's necessary to know the influence of each parameter and then develop a better welding procedure.

Resistance welding consists in flowing an electric current on the parts which will be jointed, generating heat at the region of contact by Joule effect, resulting in a superficial melting at the contact surface. At upset resistance welding, the parts are pushed against each other, then, the weldment takes place (Messler, 2004)

This work aims to investigate mechanical properties of various resistance welded wire rods obtained several combination of parameter settings. Driven by achieving a weld with an optimal performance, necessary for the subsequent procedure of mechanical descaling, a comparative and statistic study was developed to evaluate the properties of the base metal and the welding joint under different welding setups.

This experiment used the Design Of Experiment (DOE), which is an important statistical tool applied for quality improvement and productivity enhancement. The tool allows a better understanding of the process and gives the direction to take a more accurate decision. The DOE has been constantly used on the industrial sector to check the operation of countless production processes, including welding, reducing the variance and a better weld joint, closer to the expected.

2. EXPERIMENTAL

The procedure was realized at a Shlatter Upset Welding Machine – M Model, and the raw material was a steel wire rod, produced by SAE J403 standard, grade 1008, with 12.7 mm of diameter. The chemical composition according the standard is shown in Table 1, establishing the maximum content of each element on steel.

Table 1. Chemical composition of the wire rod according SAE J403 1008

C	Mn	P	S
0,10%	0,50%	0,03%	0,05%

Pressure, electric current and distance between the machine fixtures, was the parameters possible of changing at the welding machine. The distance between the fixtures will be called only distance from now on. Furthermore, two groove types, squared and and K-groove, was used to compare the difference between them under resistance welding.

In order to get a more trustable result, a data collection was made to obtain the information about the possibilities of parameter changing. After the analysis, the maximum and minimum level of each parameter was established. This levels are listed on Table 2 and they were matched to produce different welding parameter configuration, as shown at Table 3.

Table 2. Parameters levels selected to be used on the welding process.

Pressure		Current (A)		Distance		Groove
Max	Min	Máx.	Min	Máx.	Min	K
12	8	11	8	8	10	Squared

Table 3. Parameters configuration used on welding procedure to

Configuration	Pressure	Current (A)	Distance	Groove
1	8	8	8	K
2	12	8	8	K
3	8	11	8	K
4	12	11	8	K
5	8	8	10	K
6	12	8	10	K
7	8	11	10	K
8	12	11	10	K
9	8	8	8	Squared
10	12	8	8	Squared
11	8	11	8	Squared
12	12	11	8	Squared
13	8	8	10	Squared
14	12	8	10	Squared
15	8	11	10	Squared
16	12	11	10	Squared

Both, pressure and distance are selected at the welding machine scale, which is dimensionless. The properties of the weld joint are highly influenced by the microstructure of the welding joint. A higher pressure is desired to expel impurities and oxides previously present at wires' welding surface (Kerstens, 2009).

Otherwise, excess of pressure and time of welding, controlled by the welding distance, is harmful for the weld joint properties, since this promotes a mild fusion at welding interface, creating a decarburized region surrounding this welding interface (Zak and Rys, 1972), so varying the welding setups, as described at Table 2, allow to reach dissimilar structure and consequently different mechanical properties. For each parameter configuration, 4 samples for each test realized for this paper.

After weldment, the joints was submitted to tensile and bending test following ISO 6892 and ISO 5173, respectively, the tensile and the bending testing standards. For a quantitative analysis, the intensity of the crack was graded from 1 to 10, where 1 is the failure of the joint and 10 is the absence of cracks. It was necessary for further analysis on the statistical software.

The data analysis for the DOE was executed by the statistic software Minitab®, using the 2-levels factorial type of design of experiment. A preview study presented satisfactory results applying the Design of Experiment tool for resistance spot welding of Zircalloy-4, evaluating similar parameters, providing an improvement on resistance welding process and optimized welding parameters (Silva and Silva, 2008).

3. RESULTS

The experiment result and the data analysis from the statistic software are discussed in the following sections.

3.1 Tensile and bending test.

Few changes were observed on tensile testing results for most of the samples, as shown at Table 4. The tensile strength from Configuration 4, under the higher pressure, higher current, lower distance and K-groove, decreased substantially.

Table 4. Experimental results of ultimate tensile strength obtained on tensile test.

Configuration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Tensile strength (kgf)	41,9	42,6	41,4	36,3	41,7	42,2	41,1	41,8	42,1	41,9	41,7	42,6	41,9	42,2	41,4	42,2

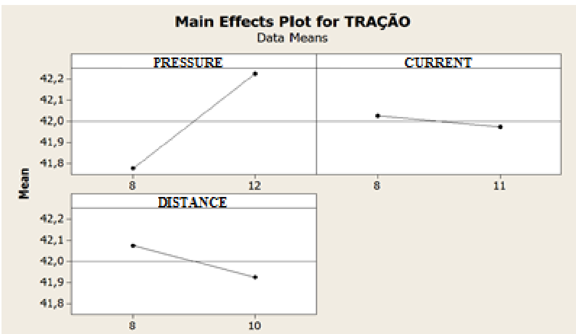
The welds subjected to the bend test are evaluated by the presence or lack of cracks after a 180º bending (Souza, 1982). Only the specimen welded following the configuration 9 has failed, the possibly reason is the incomplete joint resulted by the lower pressure, current and distance. The result of the bend test is listed at Table 5 and it was acquired by grading the bended joints, evaluating their visual appearance, verifying the presence of cracks or other relevant defects.

Table 5. Grades of the weld joints obtained from the visual inspection of the weld joint performance after the bend test.

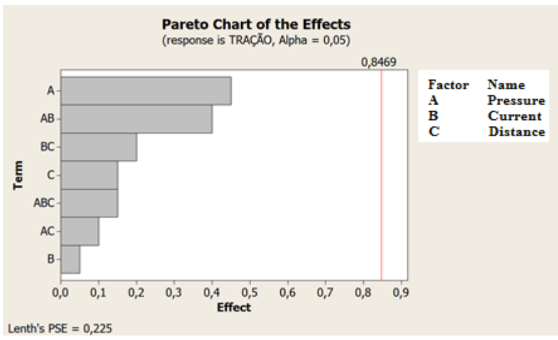
Configuration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Inspection Grade	6	6	9	10	8	7	7	4	1	9	3	3	5	10	5	10

3.2 Tensile testing for squared groove weldments analysis

The influence of the factor, or parameter, at the tensile strength of the squared groove weldments is shown on Fig. 1. The parameter that most influenced the result on test was the pressure applied on the welding. It is possible to see on Fig. 1.a, where the plot for pressure presented a greater angle and it means that the variation on tensile strength between the weldments done with the maximum and the minimum level of pressure was higher. Figure 1.b reinforces it, showing that pressure, represented by A, has a stronger effect on the result of tensile test, followed by the combination of pressure and current, represented by AB on the chart.



(a)



(b)

Figure 1. Influence of the parameter on tensile strength of square grooved welds: (a) Main effect of parameter on tensile strength, showing the fluctuation of the tensile strength for each level of each parameter, (b) Pareto chart presenting the influence of the parameters and the match of them on tensile strength.

Fixing the current was possible to evaluate the behavior of the tensile strength varying the distance and pressure. Figure 2 shows the contour plots from the three fixed currents: 8, 9.5 and 11 ampere. At Fig. 2.a is observed that fixing 8.0 A, only the combination of higher pressure and higher distance tensile strength tends to be higher, as seen at the small darker green region at the right superior corner of the chart. Raising the current, the green areas expands and the tensile strength tend to improve when distance is lower and the pressure is higher, as shown at Fig. 2.b and Fig. 2.c.

For tensile testing, the results were too close, so, there wasn't a relevant improvement on tensile strength, only a tendency to increasing, with high pressure and low distance, while current raises.

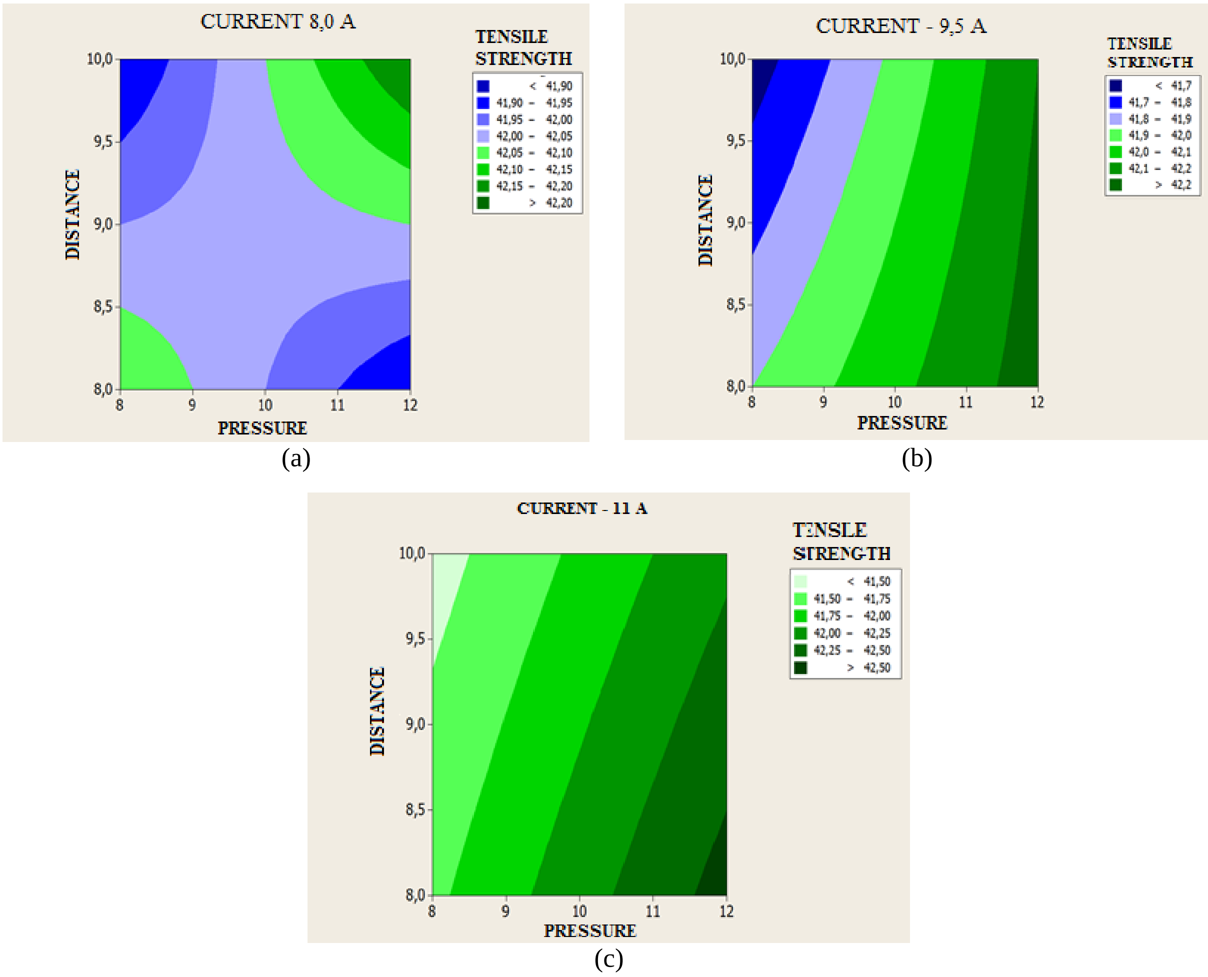
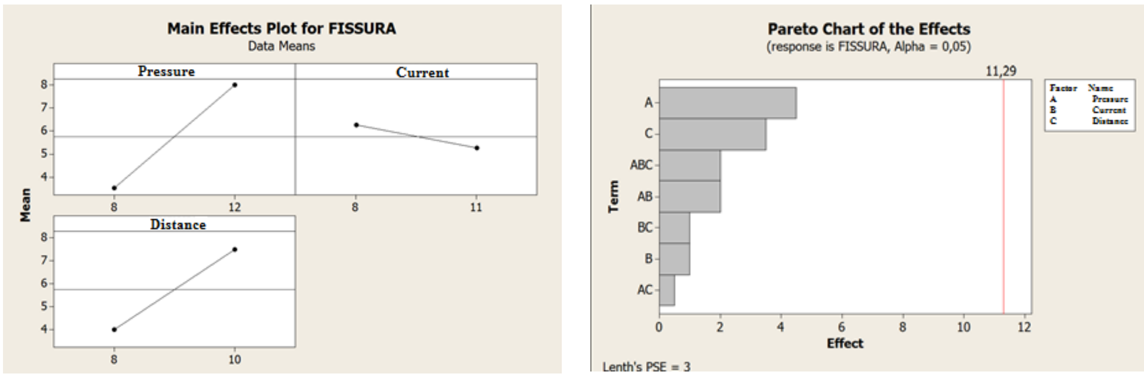


Figure 2. Contour plot chart showing the behavior of tensile strength of square grooved welds at (a) 8.0 A, (b) 9.5 A and (c) 11 A currents.

3.3 Bend testing of square grooved weldment analysis

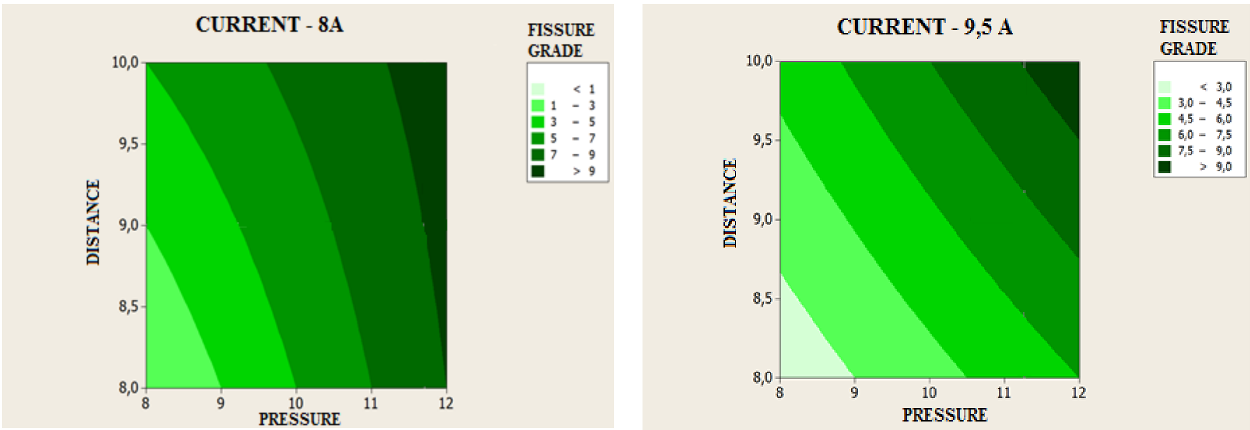
For bending test, after visual inspection and grading, comparing the fissure at the bent region as described on section 2. The data analysis of the squared groove weldments fissure after bending showed that pressure also most influenced the bending results, similarly observed on section 3.1 for tensile strength. Distance appears as the second most influent parameter. Figure 3.a shows that the weld joint is much more sensible to the pressure and distance variation. Both, pressure and distance influence, are seen respectively as A and C at the Pareto Chart on Fig. 3.b.



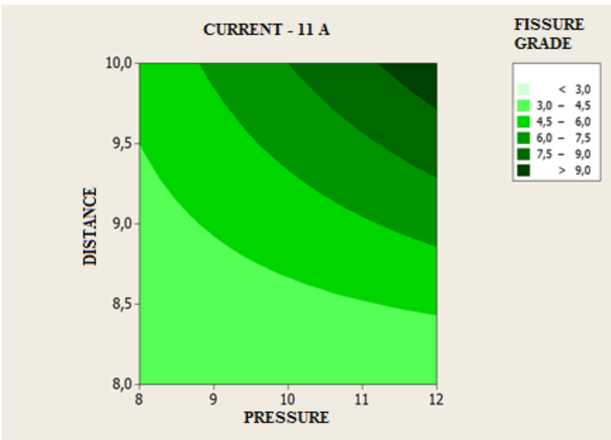
(a) (b)

Figure 3. Influence of the parameter on fissure formation on square grooved welds under bending test : (a) Main effect of parameter on bending test, showing the fluctuation of the grades of fissure for each parameter, (b) Pareto chart presenting the influence of the parameters and the match of them on fissure formation.

At the contour plots on Fig.4, is possible to observe the decrease of the bent joint as the current increase. With 8 A current, a wider dark green area is observed, at the superior right corner of the chart on Fig. 4.a. This represents grades above 9, in other words, the best result possible on bending test, the absence of cracks. As the current raises to 9,5 A and 11 A, the darker green area diminishes, as seen on Fig. 4.b and Fig. 4.c. So, the best configuration of the welding parameter, using the squared groove, high pressure and distance with low current.



(a) (b)



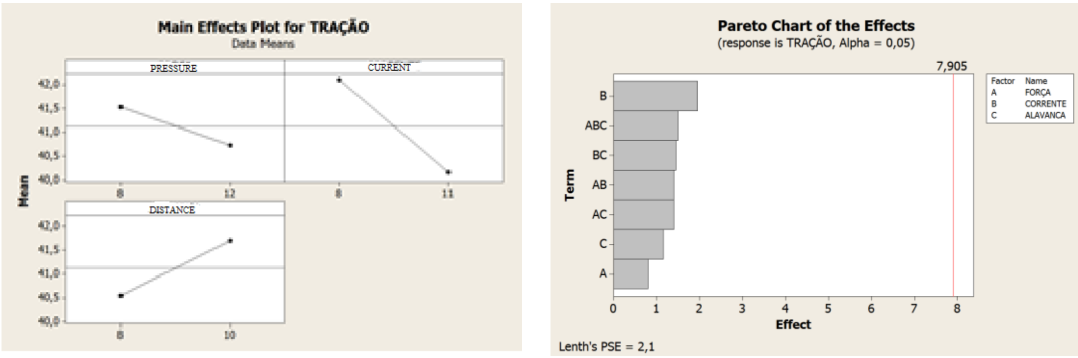
(c)

Figure 4. Contour plot chart showing the fissure aspect on bending test of squared groove welds with (a) 8.0 A, (b) 9.5 A and (c) 11 A currents.

3.4 Tensile testing for k-groove weldments analysis

As same as occurred for the squared groove, the results of the tensile test for k-grooved welds didn't had substantial variation. In this case, as seen on Fig. 5, the current was the parameter the most affected the tensile strength though.

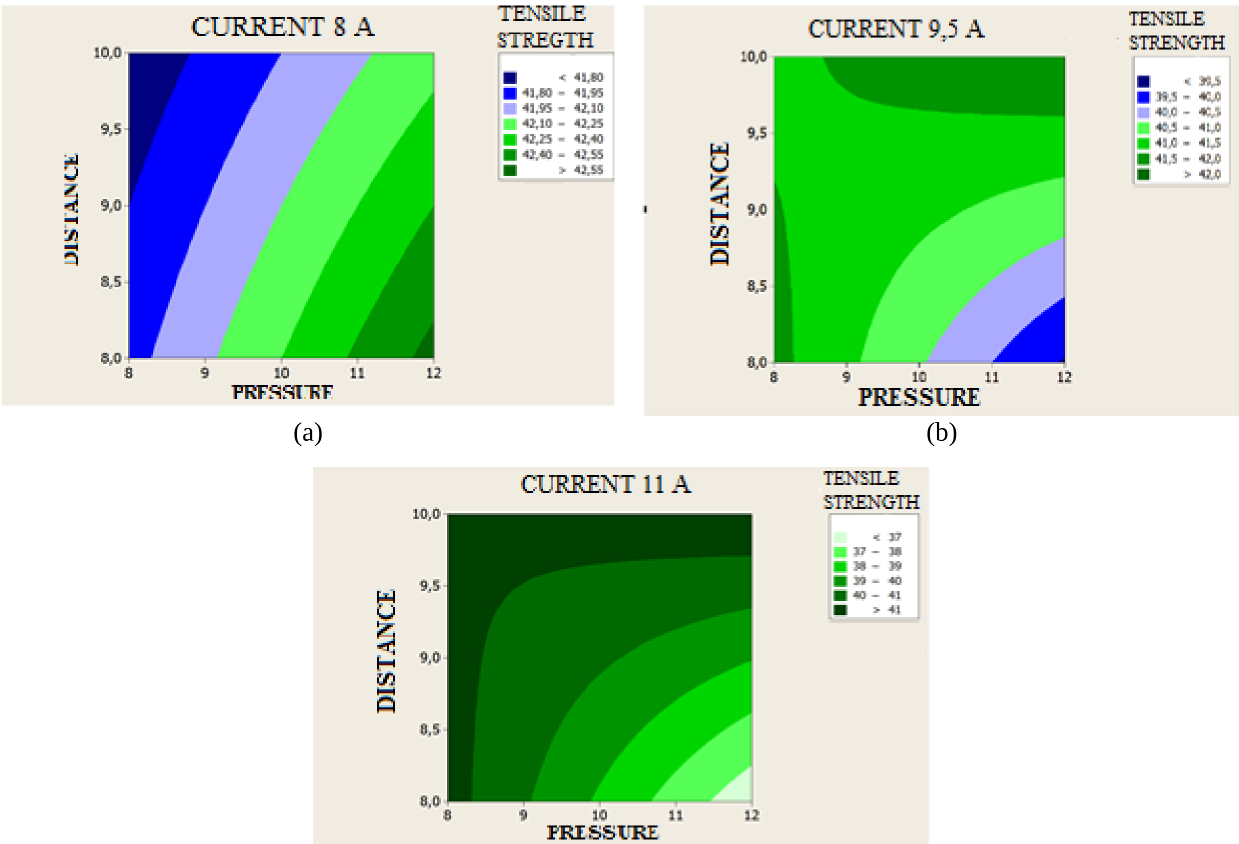
The most angled plot at Fig. 5.a, containing the bigger variation of the mean tensile strength is from the current and on Fig. 5.b, current also shows to be the most relevant parameter, represented by B at the Pareto chart.



(a) (b)

Figure 5. Influence of the parameter on tensile strength of k-grooved welds: (a) Main effect of parameter on tensile strength, showing the fluctuation of the tensile strength for each level of each parameter, (b) Pareto chart presenting the influence of parameters and the match of them on tensile strength.

Observing the contour plots on Fig. 6, is possible to predict that the wending procedure at lower current level is better for k grooved. Figure 6.a shows that most of the weldments realized at 8 A had their tensile strength between 41,8 kgf and 42,55 kgf. Only the small blue area at the superior left corner, in other words, welding with high distance and low pressure, the tensile strength was under 41,8kgf. The opposite occurs at 9,5 A and 11 A, low pressure and hig distance is desirable, and the combination of high pressure and low distance reduces considerably the tensile strength of the weld joint in the range of 37 kgf, as seen on Fig.s 6.a and Fig. 6.b.



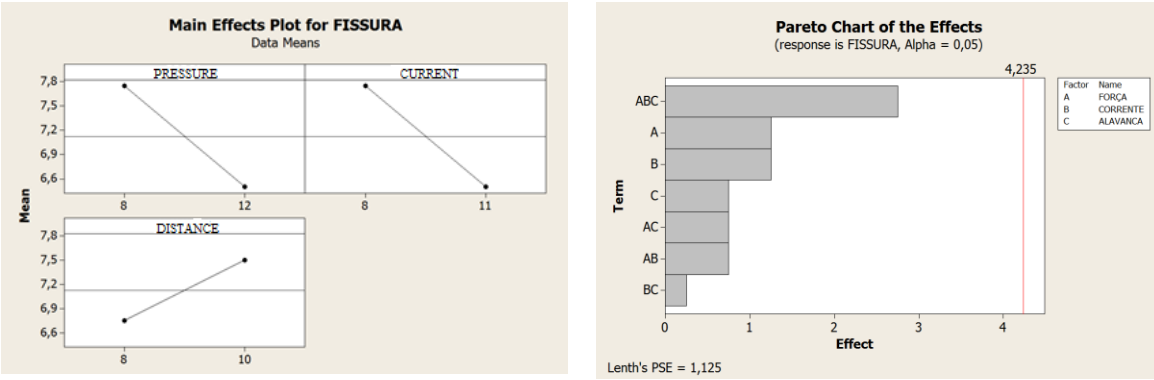
(a) (b)

(c)

Figure 6. Contour plot chart showing the behavior of tensile strength for k-grooved welds at (a) 8.0 A, (b) 9.5 A and (c) 11 A currents.

3.5 Bend testing for k-groove weldments analysis

The bending test of k-grooved welds was more affected by the combination of the three parameter, represented by the ABC column on Fig. 7.b, where A is the Pressure, B is current and C is the Distance. Figure 7.b show that the raise of the distance affects positively the fissure aspect of the welding, the same way that the decrease of pressure and current do.

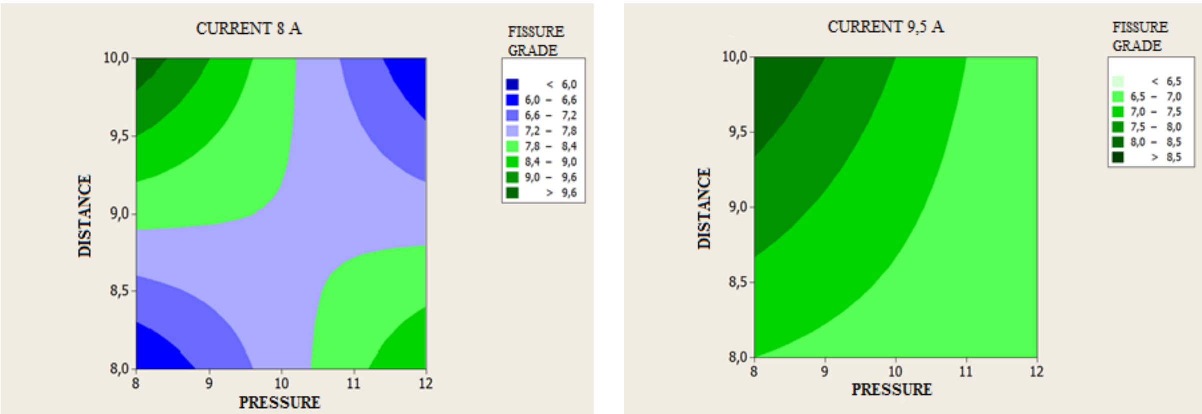


(a) (b)

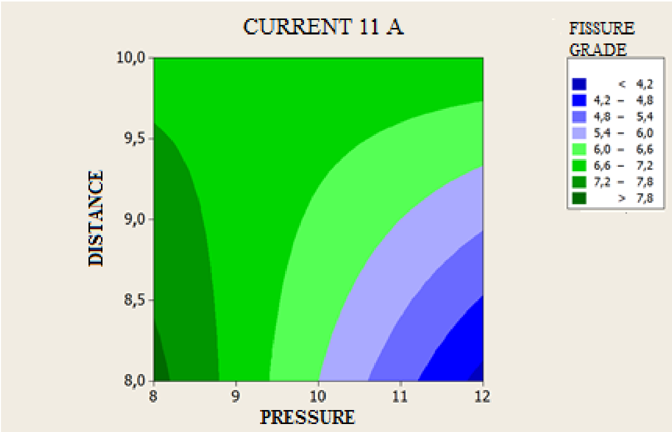
Figure 7. Influence of the parameter on bend test of k-grooved welds: (a) Main effect of parameter on tensile strength, showing the fluctuation of the tensile strength for each level of each parameter, (b) Pareto chart presenting the influence of parameters and the match of them on tensile strength.

Analyzing the tree contour plots on Fig. 8, is possible to observe that the best condition of performing a resistance welding procedure with k-groove, is increasing the distance, no matter what current is used. Although, with 8 A the bend test had superior result, as seen on Fig. 8.a, than with 9,5 A and 11 A, respectively shown on Fig. 8.b and 8.c.

Nevertheless, the results of the bend test for k-grooved welds were much inferior compared with square groove welds. Much of the area of the three charts of Fig. 8 indicates an average fissure grade around 7.



(a) (b)



(c)

Figure 8. Contour plot chart showing the behavior of tensile strength for k-grooved welds at (a) 8.0 A, (b) 9.5 A and (c) 11 A currents.

4. CONCLUSION

This work aimed to obtain an improvement of the wire rod resistance welding procedure, identifying the process parameters that most affects the mechanical properties of the weld joint, in order to optimize the welding process and assure the quality of the weld joint, reducing failures of the wire rod under mechanical descaling and wire drawing, consequently enhancing productivity.

The Design of Experiment has proven to be very useful applied for welding processes improvement. It is not only a helpful, but a powerful tool, that enables an easier and accurate data analysis.

The results obtained from the performed analysis pointed out that the squared groove welds had a better performance than k- groove weld. No significant change was observed on tensile strength of squared groove welds, however, at bending test, that simulates the weld joint behavior under mechanical descaling, the best performance was obtained at low current combined with high pressure and distance conditions.

5. ACKNOWLEDGEMENTS

To the engineer Claudine Guimarães Leite Cardoso, for her support throughout the completion of this work, as well as all operators from Votorantim Siderurgia involved on the welding of the specimens. And yet the technician of the Mechanical Testing Laboratory, for conducting the tensile and bending test. Lastly to all workers from Votorantim Siderurgia, that in some way, have contributed to carrying out this work.

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