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INVESTIGATION OF MECHANICAL AND MICROESTRUCTURAL CHARACTERISTICS PROVIDED BY HIGUCHI AND MODIFIED HIGUCHI METHOD IN BUTTERING WELDING OF AN ASTM A182 F22 STEEL WITH AN ER 80S-G WIRE.

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Abstract. *This work intends to develop experimental validation investigating, mechanically through micro hardness testing and microstructurally by optical microscopy, the predictions determined by Higuchi and modified Higuchi method, respectively, the buttering welds in three layers of an ASTM A182 F22 steel plate deposited by GMAW using an ER 80S-G steel wire. The influences of thermal cycles imposed by depositions of second and third buttering layers in the base metal HAZ were observed. It was verified that the deposition of the second layer was able to refine the HAZ-CG and temper the hard zones of base metal HAZ. It was also observed that the last layer does not interfered in the action planned by the previous heat cycle, which would result in new regions of hard areas and coarse grains, weld embrittlement areas.*

Keywords: *buttering, Higuchi, HAZ, microhardness, microstructure*

1. INTRODUCTION

The use of low alloy steel in large steel structures aimed primarily technical requirements add to the economic issues, that is, mechanical strength to lower volumes of the structure (lower weight, smaller areas), translated into lower cost (Aguiar, 2001). The use of steels with such characteristics is also inserted in the manufacturing of oil pipelines, connectors, flow regulators, valves, pressure vessels, etc. (Pereira, *et al.*, 2012; Hodgson, 2013; Pinheiro, 2014).

Many studies have been conducted to evaluate and investigate mainly embrittlement induced by hydrogen in these steels (Fallahmohammadi, *et al.*, 2014; Fenske, *et al.*, 2012; Pereira, *et al.*, 2012; Parvathavarthini, *et al.*, 2001). This phenomenon is typically the result of welding processes with high heat input, causing extensive not melted regions metallurgically modified by welding power (ZTA), resulting in a larger area of coarse grains (HAZ-GG), mechanically characterized by its high hardness, favorable condition to cracking induced by hydrogen (Oliveira, 2013).

To minimize such negative effects of thermal loads imposed on the workpiece by arc welding processes, ASTM A182-F22 in case, some techniques like buttering, overlapping passes and double layer are used (Niño, 2001; Aguiar, 2001; Oliveira, 2013). However, the use of these techniques must be done very carefully, otherwise obtaining an unsatisfactory result would be a compelling possibility.

In order to ensure that the welds conducted by these techniques are effective, Higuchi and modified Higuchi methods may be employed, predicting that subsequent layers are capable of tempering and refining, respectively, hard and coarse grain regions caused by welding of previous layers and thus reduce extensions and hardness values of these areas (Higuchi, *et al.*, 1980; Aguiar, 2001). Thus, this study aims to investigate the real effectiveness of passes overlapping and dual-layer techniques using welding conditions determined by the Higuchi and modified Higuchi methods in buttering weldments of an ASTM A182 F22 steel plate with an AWS ER 80S-G wire as a subsidy to further works using the same materials.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

An ASTM A182-F22 steel plate with dimensions of 254 x 81 x 31 mm was used as workpiece. The weld region was the area limited by the dimensions of 254 x 31 mm. The welds were deposited longitudinally along the 254 mm dimension, with 50 % of passes overlaying on each other. The filler metal used was AWS ER 80S-G of 1.2 mm diameter. Table 1 contains the base metal chemical composition. Table 2 shows the chemical composition of the filler metal given by the manufacturer.

Table 1. Chemical composition of ASTM A182 F-22 steel in percentage of elements. Iron in balance.

C	Cr	Ni	Mn	P	S	Si	Mo	Ti	V	Al	Nb
0,10 - 0,15	2,0 - 2,5	0,5 Max.	0,3 - 0,6	0,025 Max.	0,025 Max.	0,15 - 0,5	0,87 - 1,13	0,03 Max.	0,03 Max.	0,05 Max	0,01

Table 2. Chemical composition of WI M1 ER 80S-G wire given by the de manufacturer.

C	Si	Mn	Ni	Cu
0,1	0,4	1,1	0,45	0,4

Welds in single depositions were made to determine the welding conditions using parameters of previous works (Aguiar, 2001; Santo, 2013; Silva, 2015) as a basis for discerning new tension values (V), welding speed (Wspd) wire feeding speed (Fspd) and distance between piece and contact tip (DBPC) to be applied in this work, generating, thus, combinations (Tab. 3). Each of the seventeen deposits was made by automatic GMAW on 120 x 80 x 15 mm steel plates. All the welds were performed with Ar-2% O_2 shield gas.

Table 3. Welding parameters for single deposition weldments using WI M1 ER80S-G wire.

SAMPLE	Fspd (m/min)	Wspd (cm/min)	DBPC (mm)	V (V)
S01	8	35	15	30
S02	8	40	15	30
S03	8	45	15	30
S04	8	35	20	30
S05	8	40	20	30
S06	8	45	20	30
S07	12	35	15	30
S08	12	40	15	30
S09	10	45	15	30
S10	9	35	15	30
S11	9	40	15	30
S12	7	35	15	30
S13	7	40	15	30
S14	7	45	15	30
S15	7	35	20	30
S16	7	40	20	30
S17	7	45	20	30

The generated samples were cross-sectioned and characterized for hardness by Vickers testing, and regarding the extension of the regions of the HAZ, by light microscopy, meeting the criteria provided by Higuchi (Eq. 1 and 2) and modified Higuchi (Eq. 3 and 4) methods, respectively.

$$DSZ_2 > DHZ_1 \quad (1)$$

$$DHZ_2 < R_1 + P_1 \quad (2)$$

$$DHAZ\text{-}FG_2 > DHAZ\text{-}CG_1 \quad (3)$$

$$DHAZ\text{-}CG_2 < FZ_1 \quad (4)$$

Where deepness of soft zone (DSZ), deepness of hard zone (DHZ), R (reinforcement), P (penetration), deepness of fine grains heat affected zone (DHAZ-FG), deepness of coarse grains heat affected zone (DHAZ-CG) and fusion zone (FZ) are the criteria, and de subscripted numbers 1 and 2 are the first and second layers, respectively.

After the performance of welding of the second layer, a sample extracted of the cross section of the buttering. Another sample obtained by the same way after welding of the third layer. Each of these samples were mechanically tested by Vickers microhardness in three vertical extensions, starting in the last layer and ending in the base metal after the HAZ, as shown in Fig. 1. Each test was vertically distanced from each other by 0.2 mm. Results of these tests were compared in the same regions in order to observe any discrepant change in microhardness values.

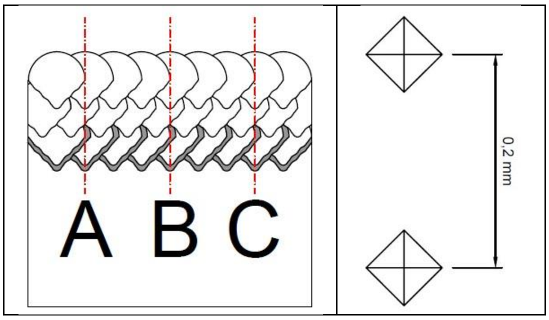

Figure 1. Schematic representation of the sequence of microhardness tests.

3. RESULTS AND DISCUSSIONS

3.1 Higuchi and modified Higuchi criteria

Each welding parameter generated particular characteristics in extensions of the hard zone (HZ), soft zone (SZ), coarse-grained heat affected zone (HAZ-CG), soft-grained heat affected zone (HAZ-GF), reinforcement (R) and penetration (P) of welds in single deposition. Figures 2 and 3 illustrates the dimensions of the geometries considered by Higuchi and modified Higuchi methods, respectively. Figures 2 and 3 shows the extensions in millimeters (Y-axis) of these characteristics in the form of column chart, facilitating the visualization of these measurement results.

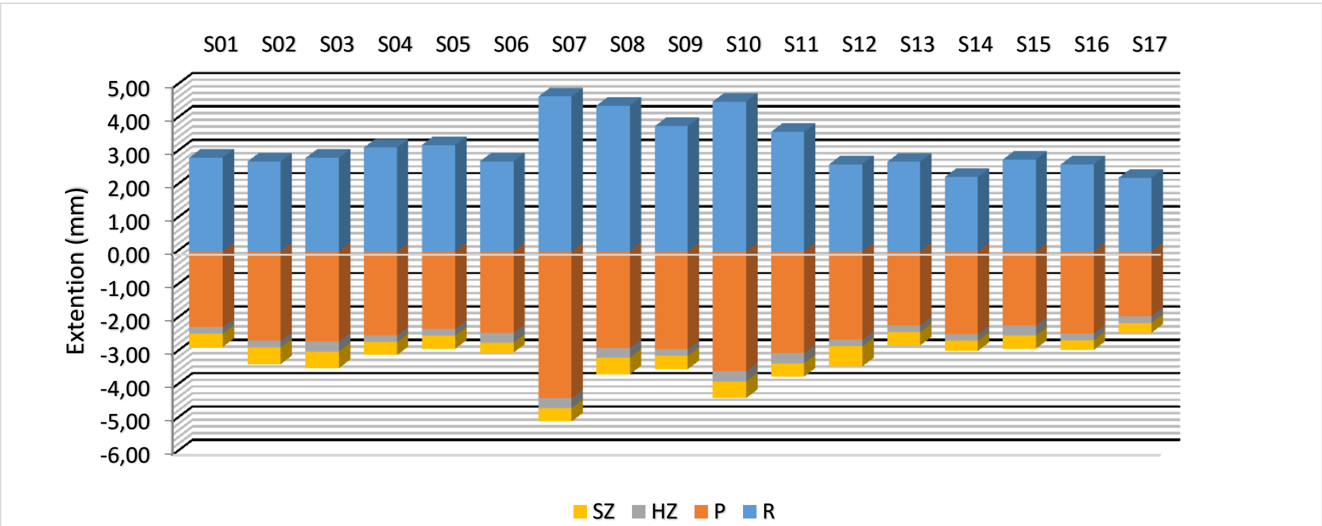

Figure 2. Reinforcement, penetration, hard zone and soft zone extensions.

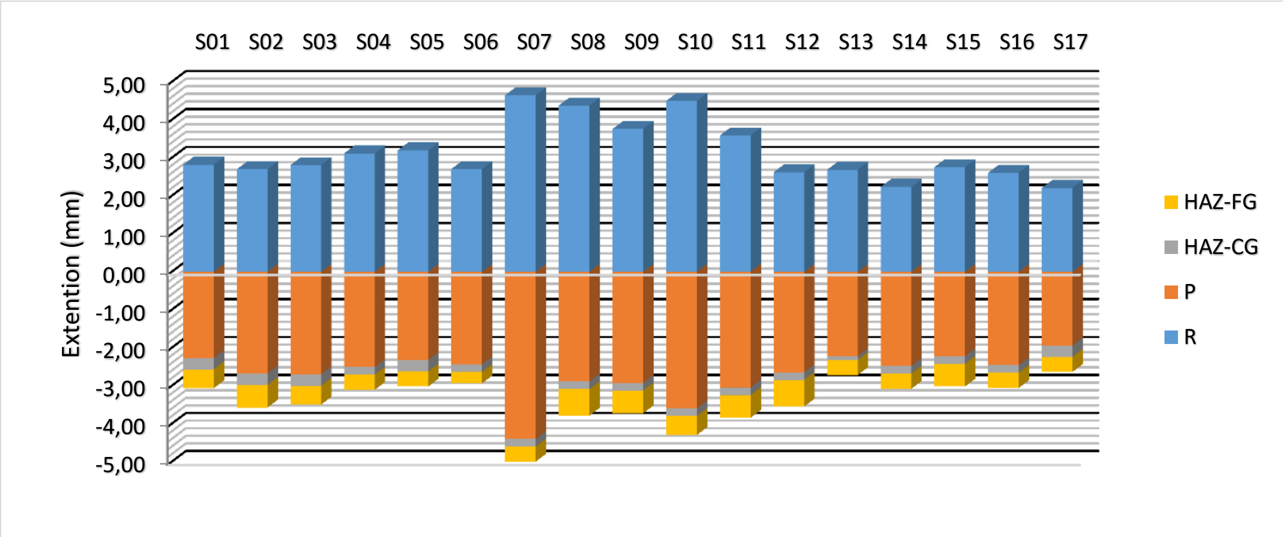

Figure 3. Reinforcement, penetration, coarse-grained HAZ and fine-grained HAZ extensions.

From the evaluations of the Higuchi and modified Higuchi criteria values, was generated the welding condition 3 shown in Tab. 4 to perform the buttering.

Table 4. Buttering weld condition.

Condition 3	
First layer	S17
Second Layer	S10
Third Layer	S07

All these results were exposed on decision diagrams, analyzed meeting the Higuchi and modified Higuchi criteria to proceed with the next phase, the buttering weldments. Importantly, these results were compared either separately or together, that is, Higuchi and modified Higuchi criteria alone (Figs. 4 and 5) and subsequently grouped (Fig. 6). Under these conditions, the selected parameters for buttering were those who generated the samples S07, S10, and S17, for the third, second and first layer, respectively. Although the S07 parameter did not meet the Higuchi criteria, this was selected to promote further reinforcement, which would guarantee a buttering of at least 9 mm.

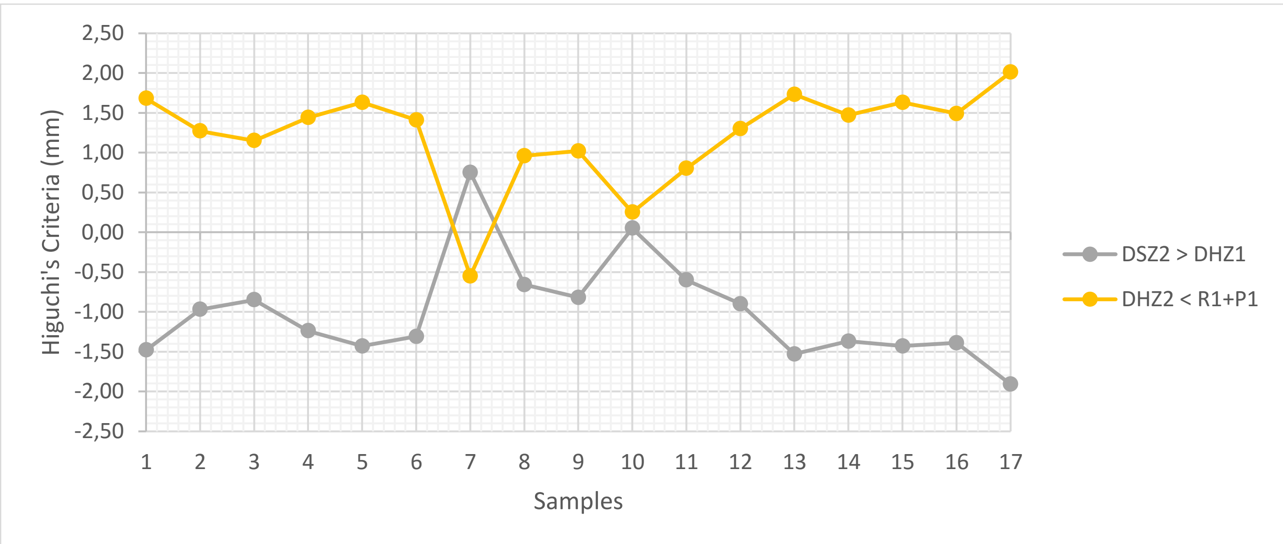

Figure 4. Decision diagram of Higuchi method.

Considering only the modified Higuchi criteria (Eqs. 3 and 4), sixteen criteria would meet it (Fig. 4). However, considering only the Higuchi criteria (Eq. 1 and 2), only one condition satisfies it (Fig. 5). From the intersection of the results of the two criteria, it is found that only one parameter satisfy them (Fig. 6). Importantly, the Higuchi criteria does not reigned in decision making, although it significantly reduces the number of parameters that can be adopted for the second buttering layer when associated with modified Higuchi for this particular case.

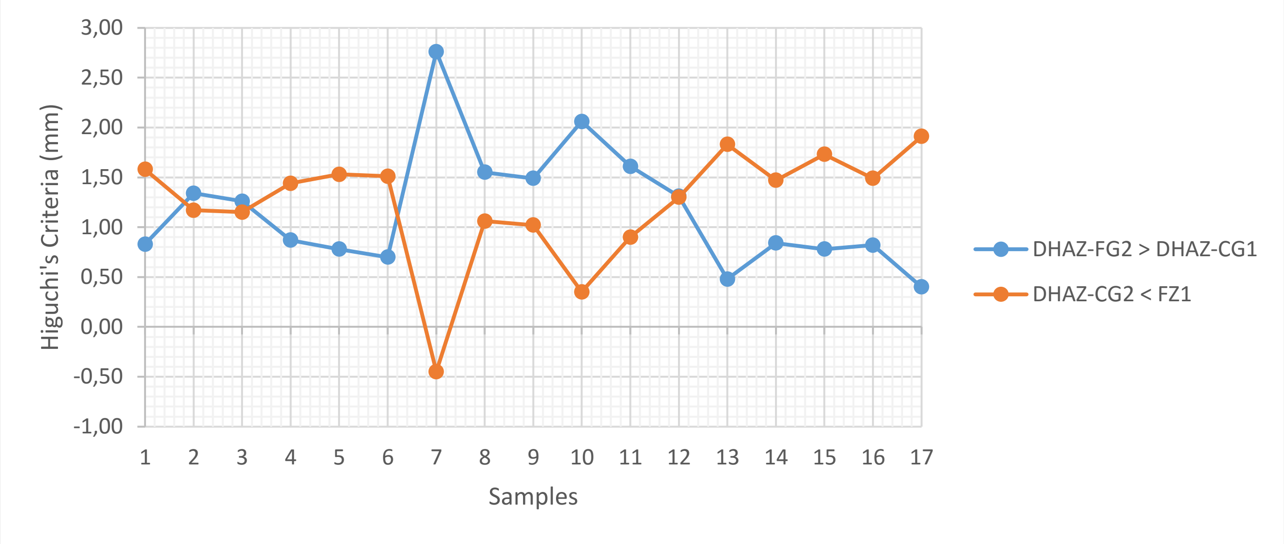

Figure 5. Decision diagram of modified Higuchi method.

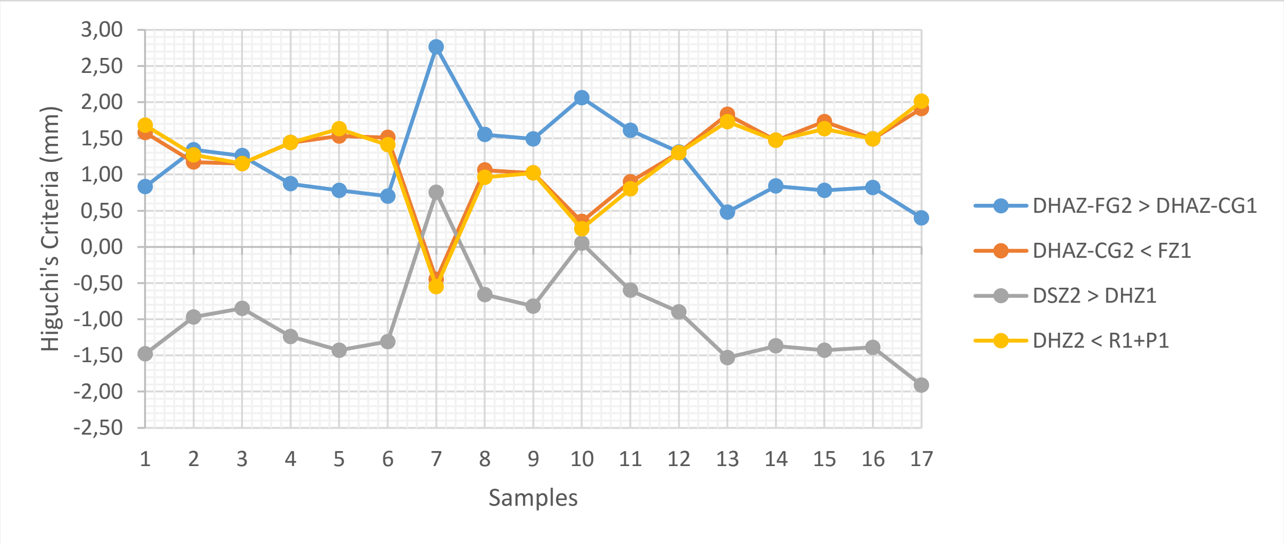

Figure 6. Grouped decision diagrams of Higuchi and Higuchi methods.

Decision diagrams for the other parameters as first layer showed the same behavior, the greater number of acceptances for modified Higuchi compared to Higuchi.

3.2 Tempering evaluation

Scans A, B and C (Fig. 1) up to fusion line indicated average hardness of 230 HV, 214 HV and 235 HV, respectively, for buttering into two layers. With three layers, the average was 236 HV, 236 HV and 239 HV to A, B and C, respectively, (Fig. 7). The numerical proximity between these values indicates consistency in the mechanical behavior of buttering, comparing the scans in the samples with two layers with their respective in three layers. The highest value of microhardness found in buttering, 256 HV, suggests a very unlikely welding present high hardness phases.

The region of the HAZ closest to the fusion line, where it is expected higher microhardness values, presented results with averages of 310 HV, 312 HV and 320 HV in two layers and 300 HV, 325 HV and 320 HV in three layers, for A, B and C scans, respectively. Microhardness values as shown in Figs. 8b and 8c, 345 HV and 318 HV, suggests tempered martensite and bainite formations, consistent with one of the phases that occur in F22 steel (bainite), that is, the microstructure next to the fusion line after buttering of two layers was at least maintained.

As can be seen in Fig. 9b, some microhardness peaks (377 HV and 375 HV) occurred near the fusion line (0.4 mm approximately). In this case, there is a discreet indication that the second layer of buttering do not tempered a small area of HAZ-CG. This occurrence was already foreseen for Lant (2001) and indicates interpass regions, matching the scanning area of microhardness tests in this particular case. Another high value (379 HV) occurred approximately 1 mm from the fusion line in the ZAC for buttering in three layers. Since this single case was detected in a region that exceeds the limit HAZ-CG promoted by the deposition of the first layer, and repeating that the second layer was able to temper the HAZ imposed by its previous, supported ratification in microhardness, it can be assumed that this value indicates a pre-existing phase of high hardness in the base metal in their state as received.

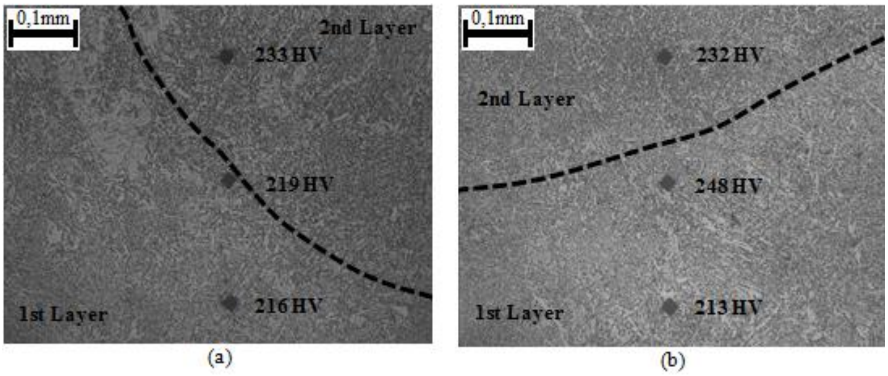

Figure 7. Microhardness values between first and second layers. Buttering with two (a) and three (b) layers. 200x. 2% Nital.

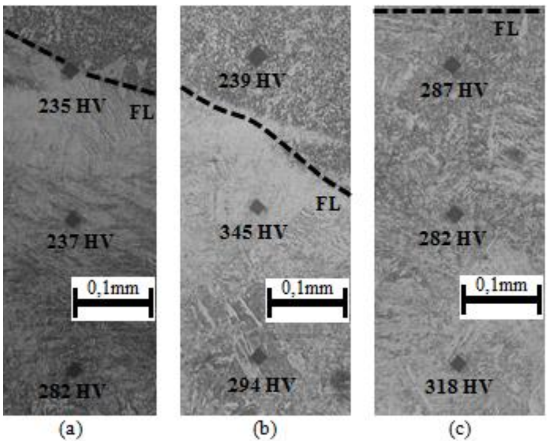

Figure 8. Microhardness values of HAZ in two layers Buttering. Scan A (a), B (b) and C (c). 200x. 2% Nital.

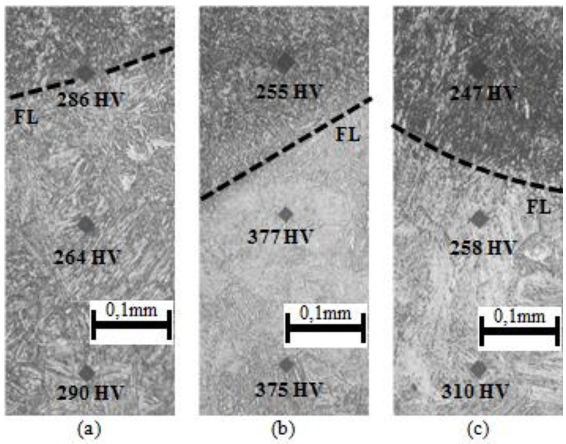

Figure 9. Microhardness values of HAZ in three layers Buttering. Scan A (a), B (b) and C (c). 200x. 2% Nital.

Table 5 shows the common behavior of microhardness in HAZ of two and three layers butterings. Is possible to see that the three layer buttering is softer in this region despite the particular case of 0.4 and 0.6 mm distant microhardness. The higher values in 0.4 and 0.6 mm distant microhardness is due to few hard phases that are present in both butterings.

Table 5. Microhardness profile on two and three layer buttering. Beginning of hard zone.

	DISTANCE FROM FUSION LINE APROX. (mm)				
	0.0	0.2	0.4	0.6	0.8
2 LAYERS	271 HV	287 HV	282 HV	318 HV	349 HV
3 LAYERS	247 HV	258 HV	310 HV	336 HV	314 HV

3.3 Refinement Evaluation

Is possible to see a region with finer grains in the first layer, after deposition of the second (Fig. 10). In these regions the first layer closest to the interface with the second (Fig. 11) we note the higher presence of acicular ferrite (AF), featuring the finest grain at these locations. This microstructure provides greater toughness weld (Fleming, 1996). A few occurrences of intragranular polygonal ferrite (PF (I)) and shorts grain boundary ferrite (PF (G)) in these regions are also indications of the smaller grain sizes of that area due to recrystallization of the extensive grain boundary ferrite (PF(G)). The few occurrences of ferrite with aligned second phase (FS (A)), characterized by forming relatively coarse grains, in those regions between layers are also an indication that the welding of subsequent layers refined prior to some extent, however, its onset in the last layer is notorious and evident (Fig. 12).

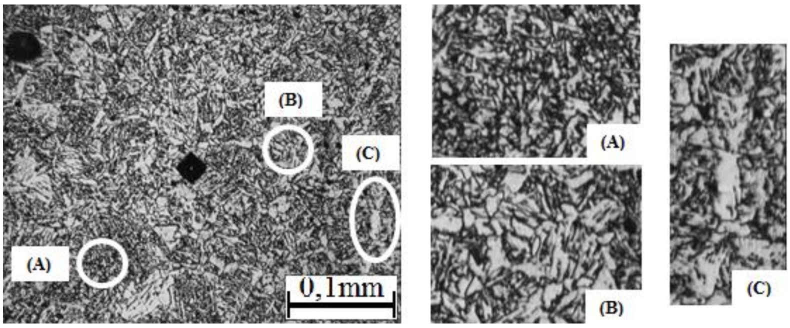

Figure 10. Refinement of 1st layer of three layers buttering B scan. (A) AF; (B) PF(I); (C) PF(G). 200x. 2% Nital.

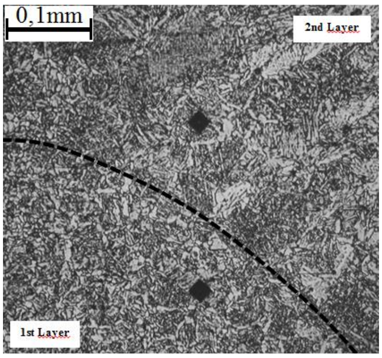

Figure 11. Interface between 1st and 2nd layers on two layers buttering B scan. 200x. 2% Nital.

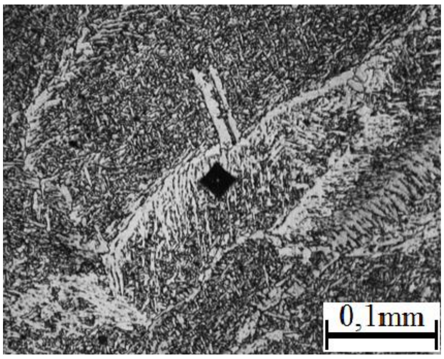

Figure 12. Presence of ferrite with aligned second phase on the last buttering layer. 200x. 2% Nital.

It is also possible to see the smallest grain boundaries in the HAZ of the base metal (Fig. 13). Note that the size of the prior austenitic grain in the HAZ region (Fig. 13a) is smaller compared to the grains in a base metal region that was not affected by welding (Fig. 13b), indicating that the refinement of grains occurred.

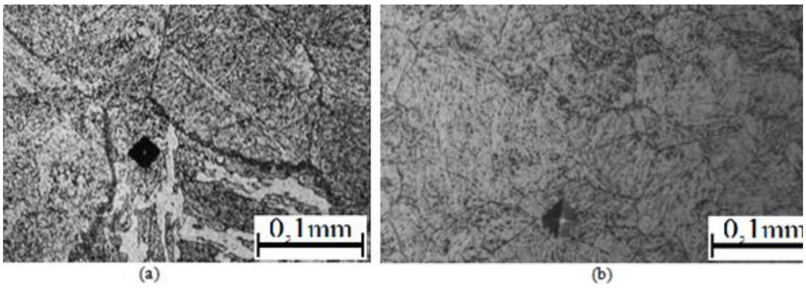

Figure 13. Refinement of grains in HAZ. (a) Region not affected 200x. (b) Heat affected zone 400x. 2% Nital.

4. CONCLUSIONS

The criteria of Higuchi method significantly reduced the possibilities of parameters associations for determination of welding conditions for the buttering layers.

Although the S07 parameter has not been considered satisfactory by Higuchi and modified Higuchi criteria, and even being the one with higher value of penetration and heat input, it not affect the refinement and tempering of the grains in the base metal HAZ promoted by deposition of the second layer of buttering.

No microhardness results within the buttering suggest the occurrence of high hardness phase as martensite.

Microhardness values between 350 HV and 330 HV in the HAZ near the fusion line may indicate the occurrence of tempered martensite and bainite in these regions, strengthening the successful implementation of Higuchi and modified Higuchi methods.

Predominance of acicular ferrite, intergranular polygonal and grain boundary ferrite next to regions between layers, and the highest occurrence of ferrite with aligned second phase in the last layers, both for buttering with two, as for the three layer, also configure the success the refinement of grains provided by the Higuchi and modified Higuchi method.

The decrease of the grain boundaries in the F22 ZTA also shows the effectiveness of the modified Higuchi method.

5. ACKNOWLEDGEMENTS

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