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## EVALUATION OF MICROHARDNESS PROFILE OF A JOINT WELDED WITH DISSIMILAR STEELS

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**Abstract.** *Structural steels have been used in various engineering applications. The use of joints welded with these steels, it becomes quite attractive. In addition, the joints can be formed with different steels, depending on the application. Thus, in the study, the AISI 8630M steel, previously butylated with the AWS ER80S-D2 (low carbon steel alloy) electrode was used to evaluate the interface between the metals involved. Microhardness tests with and without heat treatment for stress relief were performed, evaluating the interfacial regions between the metals involved, verifying the influence of the thermal treatment on the material and determining the regions of higher and lower hardness. The results showed that the buttery material presented a reduction in the microhardness when it was heat treated, with a higher intensity in the region affected by the heat, besides showing a better uniformity in the results. For final welding, used in the joint of the dissimilar joint, did not alter the microhardness of the material buttery. In this way, it was concluded that the heat treatment used helped to improve the microhardness uniformity evaluated at the materials interface.*

**Keywords:** *steel, joints welded, microhardness*

### 1. INTRODUCTION (TIMES NEW ROMAN, BOLD, SIZE 10)

The welding is used in the most of application in the engineering of components. New technology used employ new materials and fabrication conditions, such as better welding conditions. A technique for coating materials of the deposition material has improved the utilization of these new materials, as well as by joining of dissimilar material welding process. The welding process generally takes place with the application of heat, changes in microstructure can arise, are not always desirable and acceptable by causing many cases, change in properties of the welded material. The metallurgical changes suffered in the welded joint, occur during solidification and cooling of the material, being of importance, the evaluation of such phenomena, involving the welding thermal cycles. The material used was, the AISI 8630 join whit ASTM A36.

During bonding of materials by welding, the application of heat is inevitable, and changes in the microstructure of the material may not necessarily be desirable and acceptable. In addition, the temperature changes during the process cause changes in the properties of the material, such changes during the solidification and cooling of the material, such phenomena may involve phase transformations in the material and consequently metallurgical changes (MARQUES et al., 2009).

Applications with various parameters and various process conditions are observed in welding. The union between two different materials, classified as dissimilar welding, is a type of welding widely used in carbon steel joints, stainless steels and nickel alloys in oil exploration industries, for example. The application of this type of joint is justified as follows: Replacement of materials throughout use by nobler or more current materials; Use of different materials by changing temperatures along structures; Couplings of valves or components in piping.

In applications of joints welded with dissimilar materials, in regions near the melting line, occurs by diluting the base metal with the addition metal, resulting in an intermediate composition between the materials involved and the addition metal, with changes in properties related to each type of material, in addition to the influence of the addition metal on the joint composition.

## 2. METHODOLOGY FOR THE TEST OF HARDNESS AND MICROHARDNESS

For the determination of hardness and microhardness, the technical requirements specified by the API-6A (2010) and NACE MR0175 standards were evaluated, evaluating the steel AISI 8630M butylated with carbon steel ER80S-D2, with and without heat treatment and evaluating dissimilar solder joint . For the evaluation, the determination of the hardness and microhardness in the joint welded in the transverse plane to the buttery and the weld were followed.

### 2.1. Microhardness tests

For the determination of the hardness, a Mitutoyo HR-300 manufacturing durometer was used. The technical requirements specified by the NACE MR0175 and API-6A standards were followed, evaluating the AISI 8630M butyl steel and the welded joint (made up of ASTM steels A-36 and AISI 8630M). For the evaluation of the butyl steel, the test was carried out in the transverse and longitudinal region to the buttery of the plate, together with the determination of the hardness in the joint welded in the transverse plane of the weld.

The hardness tests were carried out in 3 stages for a better monitoring and evaluation of the results in the determination of the hardness of the AISI 8630M butyl steel with and without heat treatment of stress relief, besides the welded joint, consisting of AISI 8630M and ASTM A36 steels. Table 1 shows the test plan for each situation.

Table 1 – Plane of the microhardness test

| Stage          | Condition                | Plane of test            | References          |
|----------------|--------------------------|--------------------------|---------------------|
| 1 <sup>a</sup> | AISI 8630M buttery STTAT | Longitudinal/ Transverse | API-6A (2010)       |
| 2 <sup>a</sup> | AISI 8630M buttery CTTAT | Longitudinal/ Transverse | API-6A (2010)       |
| 3 <sup>a</sup> | welded joint             | Transverse               | NACE MR 0175 (2005) |

Shown in Figure 1 and 2, the hardness test embodiment for the longitudinal and transverse regions, respectively, of the butyl AISI 8630M steel. The evaluation was verified for each condition with and without the stress-relief thermal treatment. For the purposes of analysis, the scale used in the tests was the HV hardness (Vickers), the test being initially referenced by the LF - Line of Fusion, and having the measurements in relation to the LF.

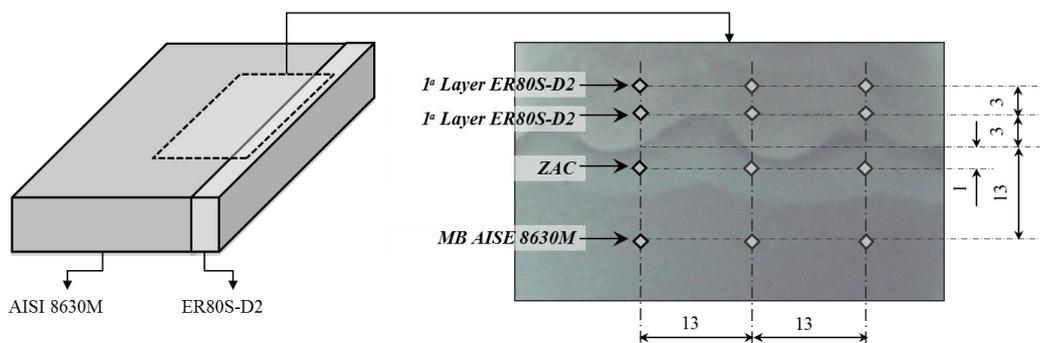


Figure 1 - Steel 8630M buttery with ER80S-D2 - Longitudinal plane of the hardness test, measured in mm.

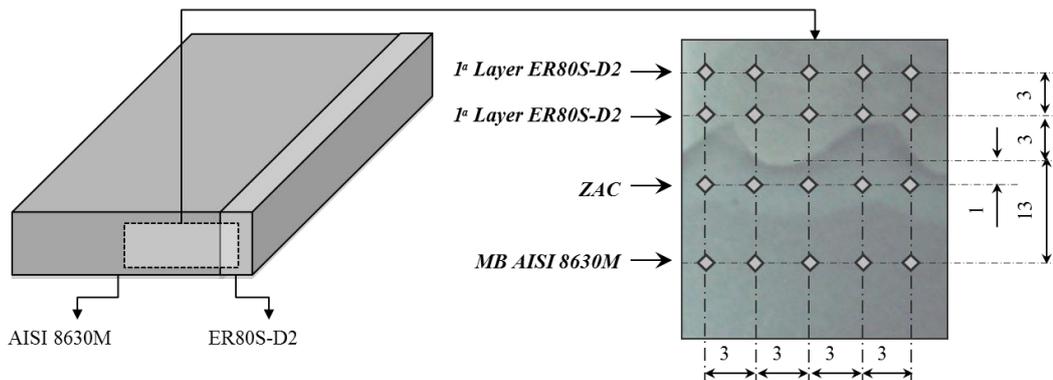


Figure 2 - Steel 8630M buttery with ER80S-D2 - Transverse plane of the hardness test, measured in mm

In the determination of the hardness along the welded joint, the same procedures of the buttery material were followed, according to the configuration of Figure 3. However, the analysis was performed throughout the joint, with emphasis on the region of greatest interest, defined as ZAC of buttery, since some fracture problems in the field were evidenced in this region.

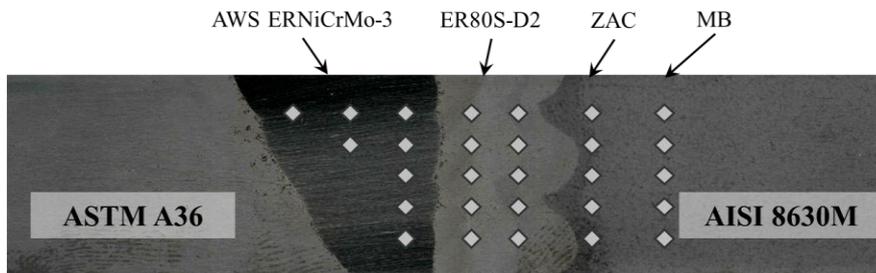


Figure 3 - Location of weld joint hardness measurements

In the determination of the microhardness, as well as of the hardness, in the buttery material and after the welding process, the study was necessary due to a better understanding of the influence of the welding process and the heat treatment of stress relief until obtaining of the welded joint, with the identification of a possible formation and location of the fragile zones along the processed material.

### 3. RESULTS OF MICRODURE TESTS

For the evaluation of the microhardness HV 0.10, the results were obtained in three conditions: butyl steel 8630M: STTAT (without heat treatment of tension relief), CTTAT (with heat treatment of tension relief) and microhardness profile of the joint welded. Figures 4.1, 4.2 and 4.3, respectively, depict the results for the mentioned conditions.

#### 3.1. Microhardness without heat treatment (8630M STTAT)

In Figure 4, the microhardness measurements of the butyl AISI 8630M steel and without the heat stress relief treatment are shown. All the tests followed the methodology of DNV OS E101 (2008) that define in three axes the indentations for the test. According to the values obtained, some values of microhardness close to the value of 350 HV are verified in the ZAC region, and that for a better control in the regions, values of this level are not recommended because they favor the possibility of fragile fracture in the material.

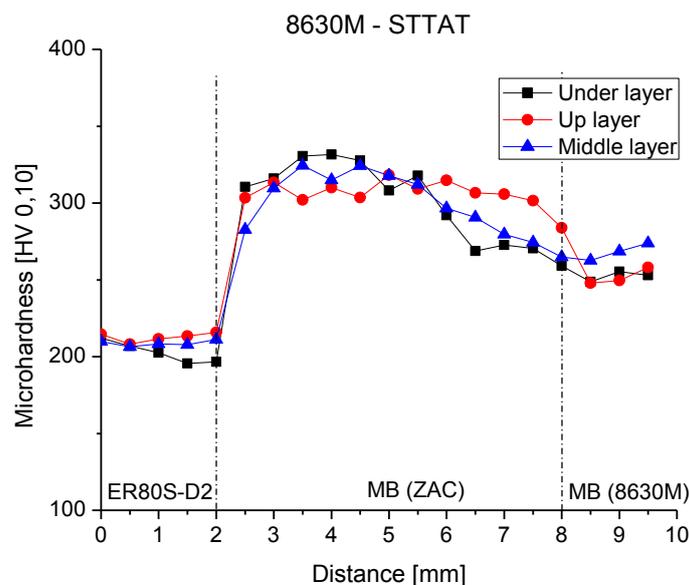


Figure 4 – Microhardness the steel 8630M - STTAT

In The Table 2, the mean and the standard deviation of the measurements performed, separated for each region, according to Figure 4, to be verified the MS (weld metal ER80S-D2), ZAC (heat affected zone) and MB AISI 8630M). In the evaluation, a higher mean value in ZAC between 2 and 5 mm is observed, with an average of 303 HV.

Table 2 – Average of the microhardness the steel 8630M – STTAT

| Region        | Average [HV 0,10] | Deviation |
|---------------|-------------------|-----------|
| MS (ER80S-D2) | 208               | 5,9       |
| ZAC           | 303               | 19,0      |
| MB (8630M)    | 260               | 10,9      |

The observation of the increase of the microhardness in the ZAC region without a stress relief thermal treatment is related to the microstructure, modified by the welding process, possibly resulting in the formation of the unconsolidated martensite microconstituent, raising the internal tensions in the region, which may favor a local embrittlement of the material. Figure 5 shows the microhardness variation in the interface region of the STTAT buttry material, with an increase of approximately 100 HV0.1 between the MS and MB (ZAC) regions, justified by the higher carbon content of the base metal, besides be a region affected thermally and with characteristics of the presence of micro-constituent of higher hardness, such as unreacted martensite.

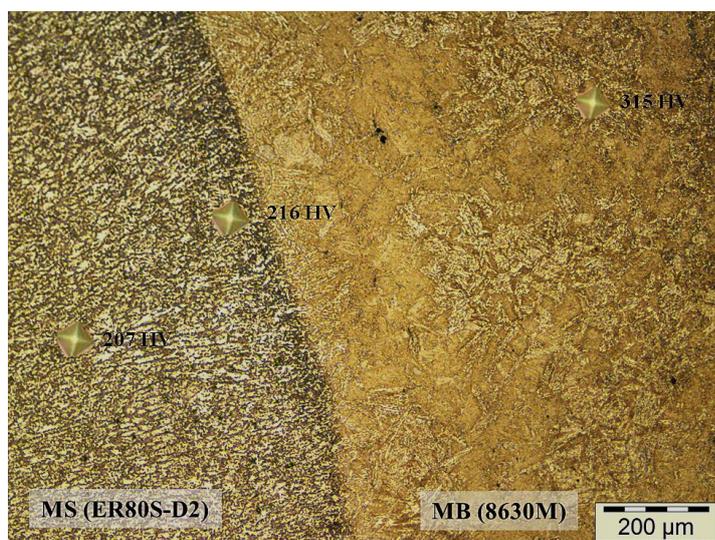


Figure 5 – Region of the microhardness STTAT

### 3.2. Microhardness with heat treatment (8630M CTTAT)

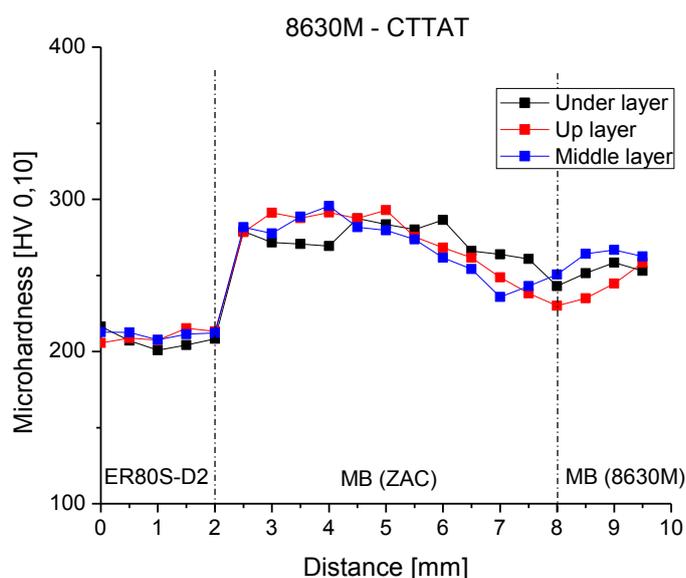


Figure 6 – Microhardness the steel 8630M – CTTAT

For the results of the HV 0.10 microhardness of the butylated CTTAT steel 8630M (with heat stress relief treatment), the values mainly showed a small reduction in ZAC, meeting the requirements of DNV RP B401. The values obtained in the CTTAT assay are shown in Figure 6. It is observed a better uniformity in the results obtained than STTAT, as well as an average value in the ZAC of 275 HV 0.10. This reduction of the microhardness in ZAC is related to the microconstituent martensite. The average values for the CTTAT condition are shown in Table 3, with a reduction in the hardness in the ZAC compared to the STTAT material, with a mean reduction of 10%, according to the action of the stress thermal treatment.

Table 32 – Average the microhardness of the steel 8630M – CTTAT

| Region        | Average [HV 0,10] | Deviation |
|---------------|-------------------|-----------|
| MS (ER80S-D2) | 210               | 4,3       |
| ZAC           | 275               | 13,4      |
| MB (8630M)    | 254               | 8,9       |

The limit of the maximum microhardness of 350 HV, defined by the standard DNV RP B401 (2010), indicates that above this value, we have the presence of martensite that is fragile, mainly under the action of hydrogen. Such control is necessary in the study, since it is directed to the region of ZAC of the buttry of AISI 8630M steel.

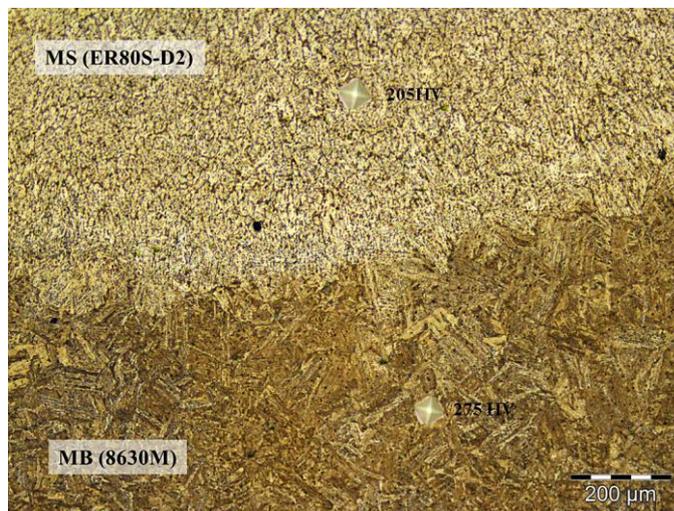


Figure 7 – Region of the microhardness CTTAT

### 3.3. Microhardness of welded joint (8630M with ASTM A-36)

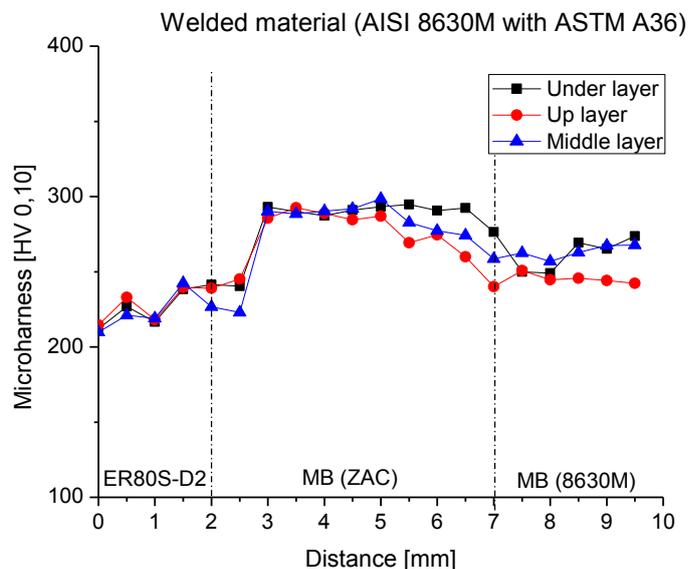


Figure 8 – Microhardness of welded joint

Following the same procedures as the butylated material CTTAT and STTAT, the microhardness results, determined in Figure 8, were determined for the weld joint.

The control of this limit, provides a smaller possibility of embrittlement of the material. It can be seen in Figure 7 the variation of the microhardness between the weld metal and the base metal (ZAC). OLIVEIRA (2013) and COSTA (2013) determined, in their studies, microhardness values in butyl AISI 8630M steel, whose results were close to those determined in the present work.

The average weld joint microhardness evaluation is shown in Table 3, with no relevant variations after welding.

Tabela 3 – Médias das microdurezas da junta soldada

| Region        | Avarege [HV 0,10] | Deviation |
|---------------|-------------------|-----------|
| MS (ER80S-D2) | 231               | 10,1      |
| ZAC           | 280               | 14,5      |
| MB (8630M)    | 259               | 11,9      |

The microhardness along the welded joint shows a similar profile to the CTTAT material, and it can be verified that the welding process between AISI 8630M and ASTM A-36 steels did not change this property, maintaining practically the same microhardness behavior.

As shown in Figure 9, the microhardness distribution: STTAT, CTTAT and welded joint are shown as a comparative effect for the conditions already mentioned in Figures 3.1, 3.3 and 3.5. This comparison shows that after welding between AISI 8630M and ASTM A36 steels, the thermal input used in this process did not influence the region of the ZAC originated by the previous buttry process, however, in view of these results it is necessary to perform the TTAT after the buttry, according to conditions studied.

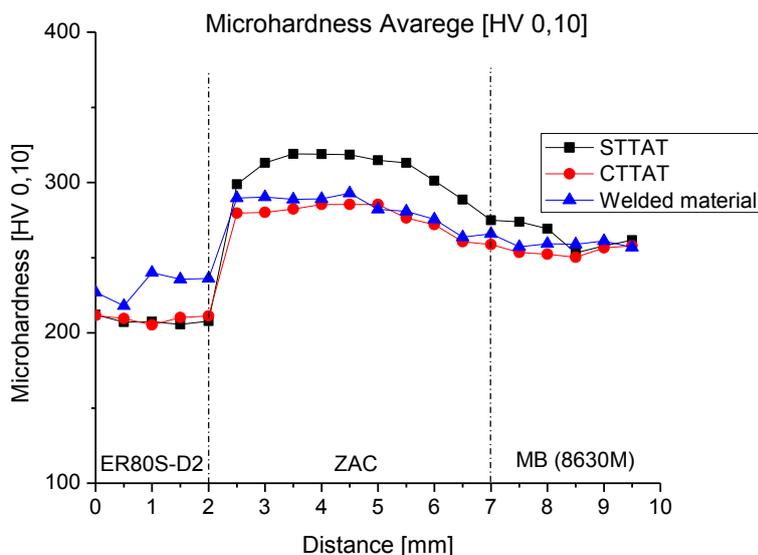


Figure 9– Microhardness of the material

#### 4. RESULTS OF TESTS OF HARDNESS

For the results of the hardness test, the material was evaluated under the conditions of the butylated and heat treated 8630M steel as well as the evaluation of the welded joint, according to the results in Tables 4.1, 4.2 and 4.3, respectively. All tests were performed based on the API 6A and NACE MR0175 standards, following the recommendations required for the evaluation of welded materials.

For the evaluation of the results obtained in Table 4.5, where the hardness distribution is verified along the butyl material (AISI 8630M with ER80S-D2) the values of higher hardness are verified in the buttry ZAC (Buttry Heat Affected Zone). The value obtained without the heat treatment of stress relief (STTAT) is reduced by approximately 12% in relation to CTTAT, confirming the influence of the proposed thermal treatment for the buttry material.

The results for the other evaluated regions, MB and MS, presented, to a certain extent, no alterations considered and with a hardness value in the HRB scale, since during the tests it was not possible to determine the hardness in the HRC scale in these regions. As the proposed study is directed to the ZAC region, our evaluation will be directed to such

region, and according to the data in Table 4, it is presented with hardness, allowing a greater possibility of embrittlement.

Table 4 – Hardness the steel 8630 transverse (API 6A)

| Condition | 1 <sup>a</sup> layer (HRB) | 2 <sup>a</sup> layer (HRB) | ZAC (HRC) | MB (HRB) |
|-----------|----------------------------|----------------------------|-----------|----------|
| STTAT     | 89,90                      | 87,65                      | 24,57     | 97,83    |
| CTTAT     | 88,65                      | 87,34                      | 21,48     | 96,42    |

In a similar way to the evaluation obtained in Table 4, Table 5 shows the results obtained for the buttery material with change in the location of the tests, as detailed in NACE MR0175. From the results obtained in Table 4.2, there is a reduction of approximately 7% in the hardness value obtained in ZAC 1, resulting in an average value of 22 HRC. For the regions of the base metal (MB) and the weld metal (MS), no major changes were observed after the heat treatment of the material, as in Table 5.

Table 5 – Hardness the steel 8630 longitudinal (NACE MR0175)

| Condition | MS (HRB) | ZAC (HRC) | MB (HRB) |
|-----------|----------|-----------|----------|
| STTAT     | 89,64    | 23,86     | 97,54    |
| CTTAT     | 87,04    | 22,00     | 95,16    |

After the evaluation of the buttery material, the final welding was carried out, and with that, the hardness was evaluated along the dissimilar joint, evaluating the variations presented after the final welding process. In this way, the recommendations of NACE MR0175 were followed, obtaining the results of Table 6. On the occasion, there is the addition of Inconel 625, as well as the formation of a ZAC 2 originated by Inconel.

Table 6 – Hardness the steel join (NACE MR0175)

| Measures | Inconel (HRB) | ZAC 2 (HRB) | MS (HRB) | ZAC (HRC) | MB (HRB) |
|----------|---------------|-------------|----------|-----------|----------|
| Average  | 91,74         | 89,78       | 86,58    | 22,74     | 97,7     |

The results obtained in the welded joint, demonstrate that the ZAC is the region of greatest hardness in the joint composition. At the time, an average ZAC value of 22.74 HRC is observed, with a slight increase in the value obtained by the material before welding. For the comparison of the other regions evaluated during the buttery, the evaluation is similar to that already commented, without great changes in the values of hardness.

According to NACE MR0175 it is recommended that the hardness value should not exceed 22 HRC. After the welding process the average value was approximately 22.74 HRC with a standard deviation of approximately 0.93 HRC. However, ISO / FDIS 13628-4 states that for some materials that have demonstrated susceptibility to hydrogen embrittlement and when exposed to cathodic protection in sea water, the hardness value may be limited to 35 HRC, satisfying the conditions found .

The elevation of hardness in certain regions of a welded joint may be a disadvantage where applicability involves use in marine structures where the maximum hardness recommended by the NACE MR0175 standard is 250 HV in order to avoid fragile fracture problems in the material in service.

However, the peaks of hardness found, especially in ZAC, can be minimized or avoided with the use of preheating, in order to revert the martensite formed by the previous weld bead.

Figure 3 shows a graph with the HRC hardness distribution as a visualization and monitoring effect of the ZAC region, observing that the welded joint presents a behavior similar to the heat treated material (CTTAT), showing, in the same way shape that occurred in the microhardness, the non-influence of the thermal input in the ZAC of interest. In relation to weld metal (MS) and base metal (MB), no changes were observed for the evaluated conditions, with only the influence considered in the ZAC.

## 5. CONCLUSION

In the work we can conclude that the standard deviation of the hardness conditions of the ZAC a greater variation of the values for the STTAT conditions, presenting more uniform values after the TTAT as well as the welded joint, which reinforces a better homogenization of the microstructure after the heat treatment. Another important information, showing the thermal input of the final welding process with ASTM A-36 steel, did not change the ZAC resulting from the buttery process, with no microstructural changes and no hardness and microhardness of the evaluated region.

## **6. ACKNOWLEDGMENTS**

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