# RESIDUAL STRESS INVESTIGATION IN ROLLED STEEL PLATES JOINED BY SHIELDED METAL ARC WELDING PROCESS

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**Abstract:** *The evolution of mechanical systems and parts that compose them need more elements that resist stress and changes in the environment which it is inserted, often harmful environment to the life time of an element. By this challenge, designing parts and components that are effective and durable, becomes a increasingly demanded, because increasing the life of a part means, as example of an industry, to reduce maintenances costs and avoid unexpected downtime in a row production. This investigation aims to evaluate, using the indentation method, the nature of residual stresses in specimens from two types: welded with correct parameters and welded with no correct parameters. When a weld process occur, internal residual stresses arise, which remain in the structure after the welding operation. Residual stresses are generated by localized partial flows that happen during the welding process. Qualify these tensions that arise to restore the balance of the internal structure of the material when it suffers thermo-mechanical changes, becomes of extreme importance in minimizing flaws in welded components. The research will be based on the analysis of variance using a factorial design by randomized by levels of processing and the data interpretation to determinate the differences between strains of a part welded with preset parameters and another welded without these parameters.*

**Key-words:** *Residual Stress; Welding Parameters; Indentation Test.*

## 1. INTRODUCTION

The fast industry expansion requires the incorporation of new technologies and implementations in the production process, so as to be quickly in production, few losses and get final products with quality. By this challenge, multiple fields of knowledge, linked to the industrial manufactuing, often do research and studies to improve and to develop knowledge and improvements aimed at the industrial processing. However, the search for new techniques and procedures require skills and knowledge in order to be properly developed and executed.

Among the problems worry the metal forming industry, there are the residual stresses as a factor of influence to the final quality of a product. Techniques to qualify and quantify these residual stresses have been developed over time, and fast procedures and non-destructible are fundamental to the evaluation and final inspection of a product.

Residual stresses can appear in materials which are submitted to different thermal or mechanical processes (casting, welding, rolling, forging, machining, bending, quenching etc.). A major cause to its presence is the occurrence, along a piece, of non-uniform plastic deformation, which might be caused by both mechanical and thermal effects. A simple example is the presence of residual stresses in a piece done by processes such as grinding or shot penning, which cause the plastic flow of material near the surface [Marques, 2009].

Residual stresses can influence the behavior to the fracture of welded joints, so that the control over them is of fundamental importance for the safety of an entire structure. One way to significantly reduce them is by the search and determination of optimum of operation parameters. Finding these parameters is a hard task, since that operations involving the manufacturing are influenced by several variables: yield stress of the material and its behavior related to to temperature, maximum temperature of heating, cooling rate, external forces, pre-heating among many others inherent to their respective manufacturing processes.

The residual stresses appearance can be also related to the internal forces balance of a component, noticing that passing through a manufacturing process, the original metal will receive thermo-mechanical modifications to turn into its final form creating, in that way, an imbalance of internal structure.

With this, stresses arise as a mean to restore this balance, nevertheless, its presence may be detrimental to a structure, as can also be an attenuator, since the evaluation of the nature of the stress (compression or tensile) and the conditions that the component will be subjected (rotation, torsion, axial loads, among others). Furthermore, they may distort the internal structure of the material, generating the warping in a component so as to reduce its service life.

## 2. FUNDAMENTATION

The Shielded Metal Arc Welding – (SMAW) process, as known as handy welding electrical arc, is the most used among the various welding processes. The welding is performed with the heat of an electric arc maintained between the edge of a shielded metal electrode and the workpiece. The heat produced by the arc melts the base metal, the electrode core and the shield. When the drops of molten metal are transferred across the arc to the weld pool, it is protected from the atmosphere by gases produced during decomposition of the shield. The molten slag floats toward the surface of the weld pool, which protects the weld metal from the atmosphere during the solidification.

Welding is a process frequently used in various structures such as bridges, aircraft, pressure vessels, offshore structures and pipelines, among others, allowing permanent unions of materials. Welded structures are often subjected to cycle loadings and may suffer a fatigue process that represents one of the most common fails in welded structures (Xiaoyan et. al., 1996). The life of a welded structure is usually governed by the required time for beginning and growth of a crack from discontinuities or pre-existing stresses concentrators, in which an unstable crack growth results in the occurrence of fracture (SHI et. al. 1990).

A study on how to minimize the residual stresses in mechanical pieces generated by manufacturing processes is necessary given that they are the main causes of failures. From this point, controlling and minimize the effect of residual stresses in a component increases life, providing less setbacks and significantly reducing replacement costs and maintenance of systems which contains welded parts.

Once that exists the necessity to reduces failures caused by residual stresses in welded component, this research contributed to the mapping and determination the residual stresses nature (tensile or compressive) induced by the welding in the part, using the indentation test evaluate it. The comparing of the results, via Brinell Hardness Test, allows classifying the residual stress nature.

## 3. MATERIALS AND METHODOLOGY

It is known that the weld operation is characterized by the localized extreme heating, and that its submit the material to localized volumetric variations, besides the transformation and properties changes in the micro and macro structures. A qualitative analysis of residual stresses in welded pieces by the shielded metal arc weld process following the correct conditions was done.

### 3.1 Materials

- Materials to this research were the SAE Steel 1020 cut in a square plate form, with 100 mm of length and 3.3 mm of thickness. Three test specimens were welded in appropriated condition and other three were welded in non-appropriated conditions .
- The electrode used was an AWS E6013, due the standard specification AWS 5.1 to welding in plates and elements of ordinary steel with low-medium carbon and small thickness. Because of the plate thickness, the electrode chosen was the one with 2,5mm of diameter which allow an operation range between 60A e 100A, with the best working value of 85A. That is the appropriated condition.

### 3.2 Methods

### 3.2.1 Separation of the specimens for welding

Initially, a lot of three plates 100 mm x 100 mm was separated to be welded in the appropriated conditions. Another group of three test specimens was selected to be welded out of that specifications. Figure (1) illustrates the samples before the welding.

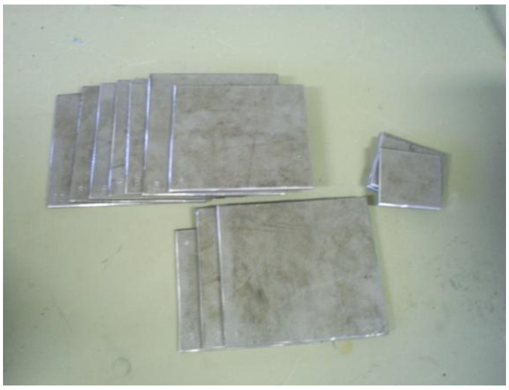

**Figure 1. Test specimens as received before the welding.**

### 3.2.2 Plates welding

The specimens with dimensions of 100 mm x 100 mm to be welded were cut in half and after that they were adequated cleaned  to ube submitted to the union process. The current used was an alternated current and the workpiece was set with reverse polarity. The machine was adjusted to a current of 85A, respecting the current range specified by the manufacturer to the used electrode, in this case the E6013. Because the nature of test specimens (plates), the joint used as abutting joint without notch with a root of 2.5 mm. This value was defined based on plate thickness, as Table (1).

The specimens were welded using the same procedures, but a priori, we used ideal parameters, i.e. the correct current as specified by the manufacturer.

The welding procedure was initially performed using the ideal parameters. We made a point of weld on each edge "A" and "B ". The welding was done in one pass at "A" to point "O " and then, from the point "B " to point "O". During welding he test specimens  were free of crimping and external forces. After welding, the elements were naturally cooled in ambient temperature. Figures (3) and (4) show steps done to show the union of the elements.

**Table 1. Scaling the weld joint.**

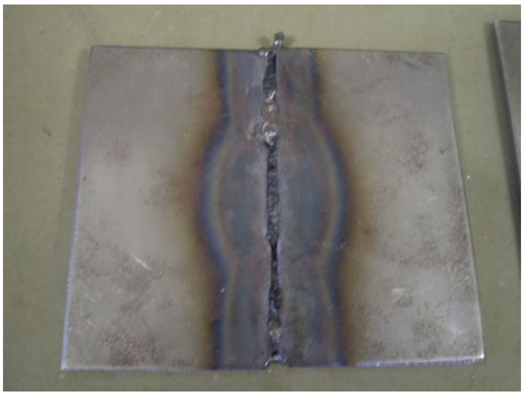

**Figure 3. Dorsal surface of the specimen in the welded state.**

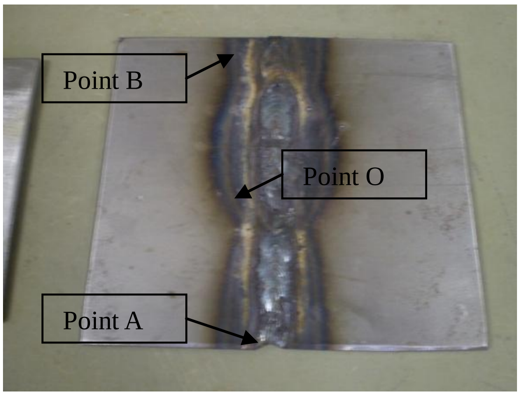

**Figure 4. Front surface of the specimen in the welded state.**

The same welding procedure was adopted for the union of specimens to be welded without parameterization, but this step we used a current of 120A for the union of elements, not respecting the condition requested by the electrode manufacturer (ideal parameters), which is the use of a maximum current of 100A. After the welding procedure specimens together received adequate treatment to be indented. A sequence of sanding and cleaning in the laboratory were conducted in the region of interest for measuring the hardness**.**

### 3.2.3 Measurement of Hardness

Initially, six samples selected for testing were subjected to sanding and cleaning. Later, they were prepared to be indented. The method used was the Brinell indentation, this method is standardized by ASTM standard E10. For the material studied, according to standard, a load of 62.5 kgf was used to puncture a steel ball 2.5 mm in diameter on the piece to be analyzed. Figure (5) shows cleaning through the full extent of the plate, 100 mm, perpendicular to the welding bead, from the right edge until close to the welding bead and the same way for the left side of the specimen.

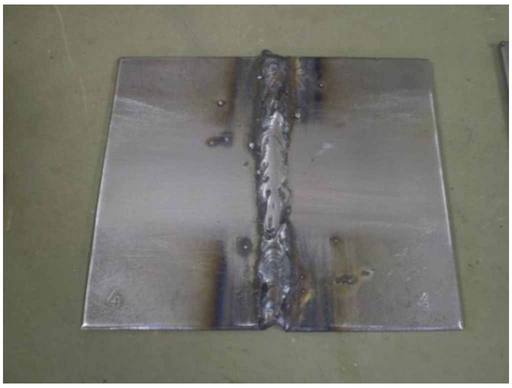

**Figura 5. Specimen prepared for indentation test.**

## 4. RESULTS

The most common method of measuring residual stresses is to use the X-ray diffraction. But a new technique has been studied, which is based on applying the indentation test on the piece. The concept of this method is that if there is residual compressive stress in the workpiece surface, and this will hinder the penetration of the indenter which indicates a higher hardness on the surface of the sample compared with a sample free of residual stresses.

Following that, there will be a superposition of residual stresses in the finished product from the various stages of manufacturing. The end result in terms of residual stresses can either increase the resistance of the product and reduce it and even did not produce significant effect.

### 4.1 Experimental Design

The two variables of influence are: (a) the type of specimen, on two levels - a welded in suitable parameters and another welded in not-suitable parameters (b) the position measured in eight levels, positions 1 to 8, as shown in Fig (6). There were three replicates at each test.

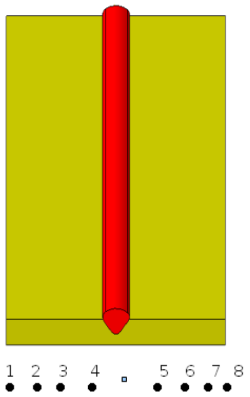

**Figure 6. Measurement position from the weld bead.**

The Table (2) shows how experimental design

**Table 2. Experimental Design.**

| | Test specimen | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 |
|---|---|---|---|---|---|---|---|---|---|
| Adequated welding process | sp1 | x | x | x | x | x | x | x | x |
| | sp 2 | x | x | x | x | x | x | x | x |
| | sp 3 | x | x | x | x | x | x | x | x |
| Non-adequatted welding process | sp 1 | x | x | x | x | x | x | x | x |
| | sp 2 | x | x | x | x | x | x | x | x |
| | sp 3 | x | x | x | x | x | x | x | x |

The data were interpreted by an Analysis of Variance (ANOVA), adopting a significance level of 5%.

### 4.2 Result e Discussion

Table (3) shows the values of Brinell Hardness for the specimens welded in ideals parameters and in non-ideal parameters, taking into account the position of the measure at 8 levels. According to analysis of variance shown in Table (4), both cases of welding (with ideal and no-ideal parameters) do not show differences in the residual stress profile, or the residual stresses cannot be detected by the means used in this work, i.e., the surface hardness tests**.** SStrat is the sum of the squares of the treatments (ideal welding and not ideal). For a significance level of 95%, the expected variance was 4.3 and was calculated at 1.401756. Therefore, it can be stated that there was no significant difference between the specimen welded with ideal parameters and the specimen welded with non-ideal parameters. We can also say that there is no significant difference between the measurement position, the confidence level of 95%. The ANOVA shows that there is no interaction between the type of specimen and position of measurement.

**Table 3. Results of Brinell hardness.**

| State | SP | Measure 1 | Measure 2 | Measure 3 | Measure 4 | Measure 5 | Measure 6 | Measure 7 | Measure 8 |
|---|---|---|---|---|---|---|---|---|---|
| Suitable weld process | 1 | 156,9 | 160,1 | 159,4 | 159,2 | 154,8 | 162,0 | 162,5 | 157,8 |
| | 2 | 159,6 | 157,8 | 160,8 | 160,1 | 152,4 | 161,0 | 156,2 | 154,2 |
| | 3 | 153,5 | 162,7 | 161,0 | 167,8 | 161,0 | 160,1 | 159,2 | 158,2 |
| Not-suitable weld process | 1 | 157,8 | 166,3 | 166,3 | 166,3 | 166,3 | 159.2 | 139 | 154.6 |
| | 2 | 157,3 | 152 | 156 | 159,2 | 151,5 | 155,5 | 151,1 | 153,3 |
| | 3 | 155,1 | 153,7 | 156 | 162 | 150,3 | 153,3 | 157,3 | 158,2 |

**Table 4. Variance Analysis.**

| | SS | GL | MSS | Fcalc | Ftab (5%) | |
|---|---|---|---|---|---|---|
| SST | 413,6 | 37,0 | | | | |
| SStrat | 100,8 | 1,0 | 100,8 | 1,401756 | 4,3 | Likewise |
| SSpos | 168,1 | 7,0 | 24 | 0,333876 | 2,5 | Likewise |
| SSAB | 72,6 | 7,0 | 10,4 | 0,144218 | 2,5 | Likewise |
| SSerror | 71,9 | 22 | 3,3 | | | |

## 5. CONCLUSIONS

The results of this study to investigate the residual stresses in welded steel SAE 1020 with ideals parameters and not ideals parameters using Shielded Metal Arc Welding Process, following the methodology and procedures, are:

1- The ANOVA results showed that there is no influence of the welding parameters on the behavior of the surface hardness profile, when comparing both cases of welding (ideal and no-ideal).
2 - Using ANOVA, we can conclude that there is no significant difference between the hardness measured in each position (1 to 8) in each test specimen. I. e., the hardness near the center was statistically the same at edge of the plate. This occurred to plates welded in ideal condition as they welded in no-ideal conditions.
3- Finally it is conclude that there was no interaction between the measuring position of the welding parameters. That is, hardness do not change its intensity on each position when welding occurs in ideal or no idal condition.

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