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ANALYSIS OF THE INFLUENCE OF GTAW WELDING PARAMETERS ON THE MICRO HARDNESS OF DUPLEX STAINLESS STEEL UNS S31803

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Abstract. *The study investigated the effect of GTAW welding parameters on the microhardness variation of duplex stainless steel UNS S31803. Controlled welding was performed on 12 samples, varying shielding gas, preheating temperature and current type. The results showed an unexpected point increase in microhardness in some regions of the samples, attributed to the formation of chromium phase precipitates, such as α' (alpha line) and chromium nitride (Cr2N), due to the chemical composition, time and temperature of heat treatment. This increase in microhardness can make the material more brittle, which is undesirable in some applications, making special care necessary during the welding of this type of material.*

1. INTRODUCTION

In today's context, some materials, such as steels, are commonly classified based on their chemical composition. For instance, SAE 1080 carbon steel is identified by its composition, which contains approximately 0.80% carbon. Other materials, like stainless steels, can be differentiated by the metallurgical phases they exhibit in their microstructure. Stainless steels can exist in three distinctive phases, each characterized by the predominant constituent in their microstructure, namely martensitic, ferritic, or austenitic (Lippold and Kotecki, 2005).

These steels are characterized by their high resistance to corrosion (rust) in a variety of environments, especially in the common where one lives. They are steels that have special and particular properties because it has as its main alloying element the Chromium, in a concentration of at least 11% in its total composition in the element, as described by Callister (2008). These steels still have some other elements added to their composition in order to allow strength in greater numbers of environment. Still he describes that stainless steels have three characteristic phases, which takes into account the predominant constituent in the microstructure, whether they are martensitic, ferritic or authentic.

A duplex stainless steel is a type that joins two phases, being ferrite and austenite, divided in practically equal proportions in order to have some advantages, especially in weldability. Its chemical composition varies greatly, being composed of about 18-25% chromium, 3-5% nickel and up to 3% molybdenum. These steels are increasingly taking space in the petrochemical industry, making them superior to austenitic and ferritic, as their duplex structure assimilates properties of both austenitic and ferritic.

The welding process in stainless steels does not differ so much from ordinary steels, in a way, as stainless steel has distinct characteristics, it needs greater care, such as having a shorter arc possible in order to overcome any possibility of alloy loss through the arc (Shek *et al.*, 1996). When a steel goes through the welding process it is exposed in the region where the weld occurs and near it there are high temperatures, and can often change some properties present in the material, a similar process when it is performing a heat treatment on a material. From which the material is exposed to very dangerous temperature ranges, some phases may arise by precipitation causing harmful effects to the material (Pratti, 2016).

A property that suffers a lot from the process is the hardness, which is very important when subjected to efforts mainly in the petrochemical industry, so the increase or decrease of the same by any process must be well evaluated in order not to compromise its application.

This work has as main objective to study the effect of GTAW welding parameters on the microhardness of duplex stainless steel UNS S31803 and evaluating the unexpected variation of microhardness results when going through the welding regions.

2. METHODOLOGY AND MATERIALS

2.1 Materials

The material used to carry out the studies was previously used in the work of Santos (2016) for other types of analyses. The material used by him was a commercial plate UNS S31803, with the dimensions of 144 mm long and 50 mm wide. The chemical composition of the material sent by the manufacturer can be viewed in Table 1.

C	Mn	Si	P	S	Cr	Ni	Mo	N ppm	Ti	Cu	Co	PREN
0,016	1,82	0,33	0,027	0,001	22,45	5,34	3,023	1544	0,0014	0,2397	0,111	34,898

Table 1. Chemical composition of the sample.

These samples went through several processes before microhardness tests were performed, such as cutting into smaller samples, sanding, and other processes. Following the following in a similar way to the methods used by Santos (2016).

2.2 Methods

2.2.1 Sample preparation

The steel bar shown above was subsequently cut and separated into twelve samples of dimensions of approximately 50 mm in length, 72 mm in width and 1.8 mm in thickness. Usually, after welding, a device is used for post-welding heat treatment, in which a heating system through inductive effect is used. This procedure induces an intense localized heating, which, for the case, would hinder temperature control, taking into account that heatings in the order of 1050 °C are reached in times of 10 seconds. This device is known as a conical heater and was used by Santos (2016) to heat the samples. Heating curves were raised in order to perform heating tests so that through the curves obtained the approximate times to reach 200°C and 300°C. These two temperature ranges were chosen for the fact that they would act by decreasing the cooling rate of the welded plates, while not being temperatures where precipitation of secondary phases occurs.

Table 2. Temperature x Warm-up time.

Temperature	Time
200ºC	11 min
300ºC	17 min

2.2.2 Welding of samples

For the definitive realization of the welding process, calculations were made regarding the welding energy for both types of current, pulsed and conventional. It is worth noting that none of the cases there was the need for addition metal, because the intuition of the procedure was not the union of two plates, only to analyze the influence of the parameters of GTAW welding. The torch was positioned so that the distance between the plate and the electrode was 2 mm, remaining at 90° from it. In the case of pulsed current, the balanced wave was maintained (equal base and pulse time, 0.5 s), seeking the same energy factor for both types of current. Thus the welding energy for conventional current was:
"The equation of the dynamical system is written in one of the two forms,

$$H = \frac{60 \cdot V \cdot I}{v} \tag{1}$$

Where:
H = welding energy (J/cm)
V = welding voltage (V)
I = welding current (A)
v = welding speed (cm/min)

And for pulsed current it was:

$$H = \frac{60 \cdot V \cdot (I_p \cdot t_p + I_b \cdot t_b)}{v \cdot t_p \cdot t_b} \tag{2}$$

Where:

Ip = peak current (A)

tp = time at peak current (s)

Ib = base current (A)

tb = time at base current (s)

Thus the welding parades used for the welding of the samples were:

Welding Parameters	
Welding Speed	60 cm/min
Conventional Current	142 A
Pulsed Current	105 A Ib/ 180 A Ip
Tension the arc	13 V
Protection Gas Flow	10L/min
Welding Energy Conventional Current	1846 J/mm
Welding Energy Pulsed Current	1852,5 J/mm

Table 3. Welding parameters used.

Thus, after the definition of the parameters the welds were designed in a factorial arrangement that allowed to isolate the effect of the shielding gas, the preheating temperature and the current mode. Thus, two protection conditions were used, where commercial pure air gas and an experimental mixture with the addition of 10% N2 were used. The samples were then identified and organized in order to facilitate understanding, being identified as acronyms:

Gás	Current Type	Temperature	Acronym
Ar Pure	Pulsed	200ºC	PAr2
Ar Pure	Pulsed	300ºC	PAr3
Ar Pure	Normal	200ºC	NAr2
Ar Pure	Normal	300ºC	NAR3
Ar Pure	Pulsed	Environment	PArTa
Ar Pure	Normal	Environment	NArTa
Ar 90% N 10%	Pulsed	200ºC	PN2
Ar 90% N 10%	Pulsed	300ºC	PN3
Ar 90% N 10%	Normal	200ºC	NN2
Ar 90% N 10%	Normal	300ºC	NN3
Ar 90% N 10%	Pulsed	Environment	PNTa
Ar 90% N 10%	Normal	Environment	NNTa

Table 4. Identification of samples.

3 welds were performed for each condition, totaling 36 welded plates. Below is an illustration of the example of welding performed.
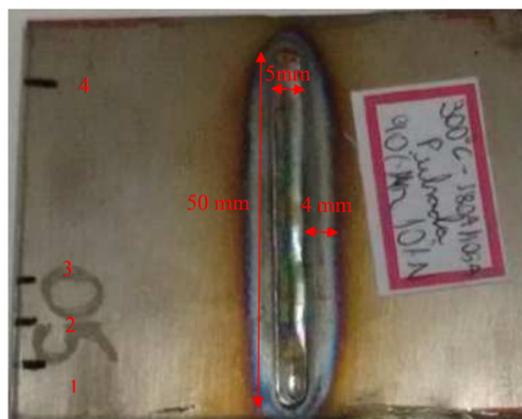

Figure 1. Welded sample.

2.2.3 Microhardness Test

Farias (2022), performed Vickers microhardness tests using a Shimadzu Microdurometer model HMV-G 20ST, exemplified in the figure below.

Figure 2. Shimadzu microdurometer model HMV-G 20ST.

The measurements were made in line through the ZF (Molten Zone), ZTA (Thermally Affected Zone) and the MB (Base Metal) along the sample, with a distance of 0.5 mm between each indentation. We performed 27 indentations in the 12 samples, evaluating each phase of the samples, some of the indentations can be seen below:
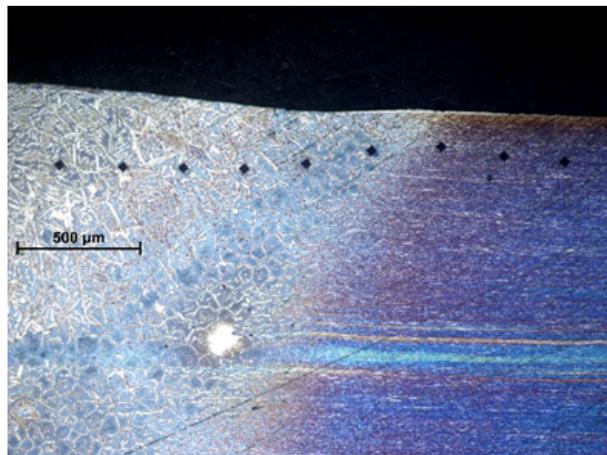

Figure 3. Sample with normal current, with pure argon and with 300 °C of preheating.

After the tests were performed, the results of microhardness were compared with the literature, in order to really understand the reason for the increase in hardness at certain points, and to understand the cause of this.

3. RESULTS AND DISCUSSIONS

The results of the trials showed some incongruities during the evaluations. A gradual increase in microhardness was expected as indentations advanced from the base metal (MB) to the molten zone (ZF), but this pattern was not observed in some samples. The samples that stood out the most in relation to the expected pattern were those that did not go through the preheating process. This suggests that the abrupt change in temperature during welding may have irregularly altered the microhardness of the samples. The results of these samples without preheating are detailed in the graphs and tables.

Regions	Samples			
	NArTa	NNTa	PNTa	PArTa
MB	264,3	240,3	258,7	243,7
	264,0	239,3	263,0	249,7
	259,7	237,7	265,3	238,0
ZTA	271,0	257,3	279,3	242,3
	277,3	253,0	270,3	239,0
ZF	289,3	257,0	270,0	243,0
	292,3	286,7	288,0	244,0
	290,3	260,7	283,7	260,0
	298,3	257,7	279,3	268,7

Table 5. Microhardness result of the samples without preheating temperature.

The graph clearly illustrates the variation of microhardness in the samples. It is observed that some indentations presented an unexpected increase in microhardness, contrary to the expectation that the results should be increasing as they advance towards the molten zone.
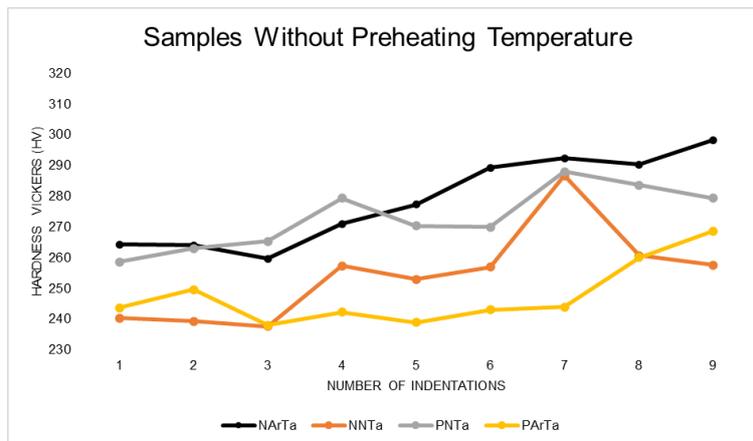

Figure 4. Microhardness result of the samples without preheating temperature.

Regions	Samples			
	NAr2	NN2	PN2	PAr2
MB	274,7	273,0	263,3	277,0
	273,3	285,7	279,0	284,7
	279,0	286,3	274,7	279,3
ZTA	273,7	298,0	291,0	269,0
	288,7	291,7	292,3	276,7
ZF	291,0	298,3	293,3	277,7
	276,3	301,3	290,7	278,0
	288,3	281,0	285,3	278,7
	280,3	313,0	301,3	280,0

Table 6. Microhardness result of the samples preheated to 200°C.

In the case of samples preheated to 200°C, the variation of microhardness did not present significant discrepancies compared to the other samples. Despite the different parameters, these samples did not exhibit the same change, which

can be attributed to the less significant impact of the sudden change during the welding process. The chart below represents this.
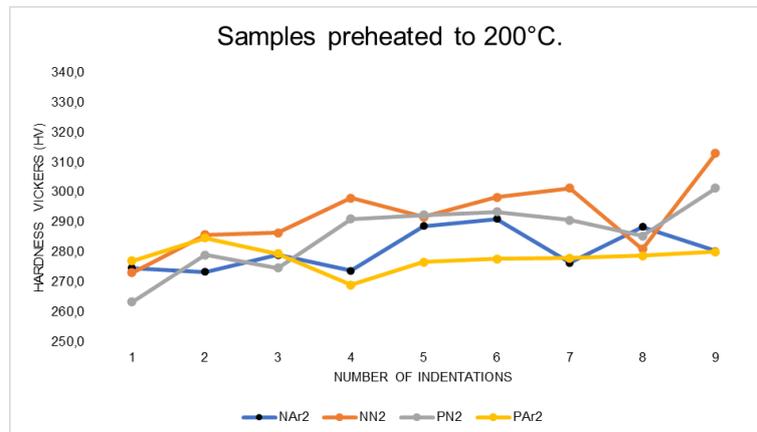

Figure 5. Microhardness result of the samples preheated to 200°C.

Regions	Samples			
	NAr3	NN3	PN3	PAr3
MB	276,3	274,0	269,3	273,7
	282,0	275,3	274,3	272,3
	283,7	272,3	279,0	273,0
ZTA	273,7	272,3	280,7	280,7
	274,3	282,0	278,3	295,3
ZF	276,7	276,7	283,0	291,3
	280,0	280,3	268,7	279,3
	285,7	283,7	282,0	276,7
	286,7	271,3	288,3	272,0

Table 7. Microhardness result of the samples preheated to 300°C.

The results of the tests on the samples preheated to 300°C were the ones that presented the most unusual characteristics. When the indentations approached the molten zone (ZF), the microhardness stopped increasing and began to decrease, resulting in a behavior opposite to that expected from the beginning of the study. The chart below represents this.
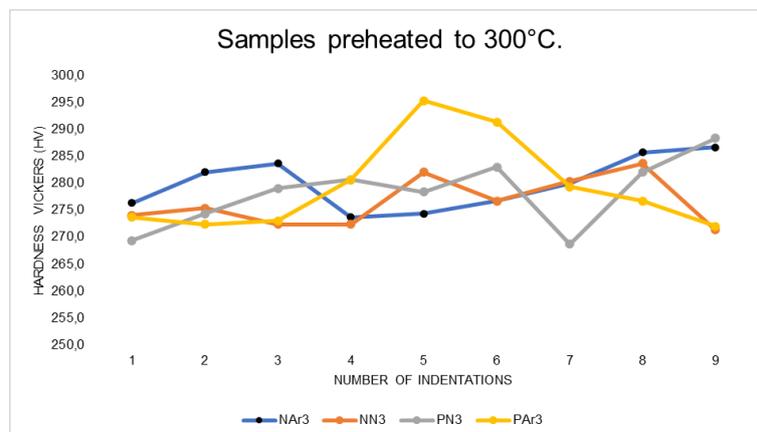

Figure 6. Microhardness result of the samples preheated to 300°C.

Based on the data, a strategy was developed to explain the microhardness variations, considering two main points as possible reasons for these variations:

- Precipitates: Due to the high levels of chromium, nickel and molybdenum, precipitation of different phases can occur, such as chromium carbide ($Cr_{23}C_6$), chromium nitride (Cr_2N), sigma phase (α) and chi phase (χ).

- Variations in the parameters: Variations in the parameters and in the welding format (pulsed or continuous) may possibly be one of the causes that irregularly affected the microhardness of the samples. Logically, this hypothesis is created from the fact that in pulsed current the sample is less affected by the heat of the process than with the direct current, since the heat transfer in this process occurs discontinuously.

To investigate these variations, we conducted microscopic analyses at specific points with the purpose of identifying potential microhardness values that would justify each of these parameters.

It is evident that the inclusion of nitrogen as a stabilizing agent in the shielding gas had a direct impact on microhardness results. The results revealed the highest microhardness values in association with the presence of nitrogen, indicating a significant interaction between nitrogen and the welding pool, resulting in a region of higher hardness.

Furthermore, it is notable that preheated samples performed similarly, with both groups exhibiting higher microhardness values when compared to samples without preheating.

The evaluation of precipitated phases in the micrographs did not yield conclusive results due to equipment limitations and available machinery. The identification and characterization of the types of precipitates present also proved to be challenging, given the complexity of the material under investigation.

4. CONCLUSION

Therefore, following a meticulous analysis of the obtained results, it is not possible to accurately pinpoint the cause of the significant microhardness variation in comparison to the expected values. Nonetheless, it can be inferred that factors such as the indentation technique can substantially alter the final outcome and obscure the true material hardness.

Furthermore, it is observed that the welding parameters have a substantial impact on the microhardness results of the samples. Higher microhardness values were found in the NN2 (Ar 90% N 10%, Normal, 200°C) and PN2 (Ar 90% N 10%, Pulsed, 200°C) samples, demonstrating the direct influence of preheating temperature and the type of gas used.

Another noteworthy point is that, in the hypotheses considered, preheated samples exhibited considerably higher values when compared to samples without preheating, suggesting that pre-treatment of the sample prior to the execution of the process can significantly affect the obtained properties.

To obtain a more precise assessment of the sample alterations and truly comprehend the phenomena at play, it is recommended to conduct chemical etching to reveal susceptible precipitation phases, such as chromium carbide, and employ more sophisticated equipment for the material's microhardness tests. This would allow for a more in-depth and detailed analysis of the material's characteristics and the observed variations in the tests.

5. REFERENCES

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