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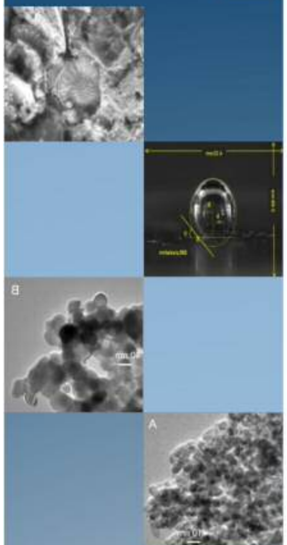

RECENT DEVELOPMENTS IN METALLURGY, MATERIALS AND ENVIRONMENT

CHAPTER 13

Effect of Travel Speed and Mixed Gas Penetration Protection on Mechanical Properties During the Manufacture of 304L Stainless Steel Tubing by the GTAW Process

P. Hernández-Gutiérrez[1]*, J. L. Acevedo-Dávila*[1]*, J.J. Ruíz Mondragón*[1]*, C.A. Guevara Chavez*[1]*, F. Cepeda-Rodriguez*[1]

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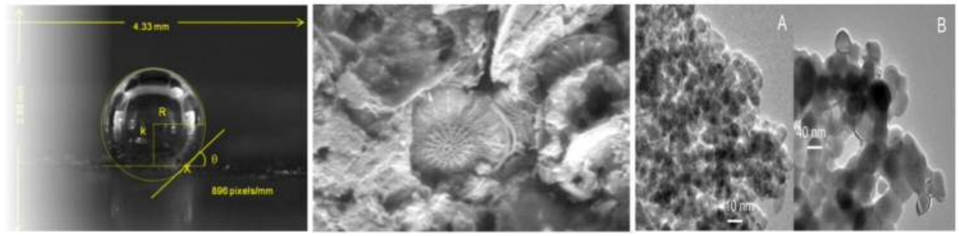

Materials

CHAPTER 13

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Abstract

The austenitic stainless steels of type 304L are alloys which have carbon content below 0.03%. Applications of this stainless steel includes tubing for cooling systems in the automotive industry. The present study was conducted to evaluate the effect of variables involved in welding operations by the GTAW process of an austenitic stainless steel pipe grade 304L on characteristics as penetration and mechanical properties. Some variables to consider are travel speed and shielding gas mixture. An analysis of variance was used to determine which variable promotes the greatest impact in this process. According obtained results, hydrogen content has an important effect on penetration; mechanical properties were not affected by changing considered variables.

Keywords: Penetration; Hydrogen; Welding Travel speed; Stainless steel

1. Introduction

Stainless steels are iron-based alloys, with variable contents of chromium, carbon and other elements, mainly nickel, molybdenum, silicon and titanium, which give them a particular resistance to some types of corrosion in certain industrial applications [1]. Resistance to corrosion and oxidation is a feature of these alloys related to passivation phenomenon corrosive and oxidizing environments. Passivation can be described as the formation of a protective surface film of chromium oxide.

Stainless steels are complex alloys and can be classified in five basic groups according to their metallurgical structure: austenitic, ferritic, martensitic, duplex and precipitation hardening [1]. A common problem related to stainless steels welding in called sensitization: the carbon in the steel reacts with chromium promoting the formation of chromium carbides as precipitates at grain boundaries in the areas affected by welding heat. The local loss of chromium from the interstitial region to the carbide particles allows preferential attack of intergranular corrosion and then said that the steel is sensitized, or suffering a weld decay [2]. Austenitic stainless steel type 304L, a low carbon modification of type 304, is able to reduce carbide precipitation during welding.

Gas tungsten arc welding (GTAW) is a process with an arc between the electrode and the weld pool, protected from air by an inert gas under pressure. In general, type 304L stainless steels are weldable by common processes such as arc welding and (GTAW), shielded metal arc welding (SMAW) and gas metal arc welding (GMAW) [3]. These processes produce conventional welding cups due to moderate heat input corresponding to cooling rates which generally produce crack free welds with acceptable microstructures in steels of this type.

In the GTAW process, gas compositions have a protective role. The composition of the gas mixture depends on the material and thickness to be welded. This composition must consider the chemical-metallurgical connection between the process gas and the weld pool during the welding process. The density of the shielding gas has an important influence on the efficiency of protection of welding arc from the environment. Argon (Ar) and carbon dioxide (CO_2) are gases that have a high density and then an excellent arc protection. The hydrogen (H_2) and helium (He) on the other hand have a density 10 to 20 times lower than that of Ar and are therefore prone to turbulent flow at the exit of the welding nozzle due to thermal buoyancy [4].

For the mixture of inert gas, higher H_2 proportion gives a wider temperature distribution, an increase of heat input and a slightly reduced atmosphere [4]. Identify and predict the quality of welding through a study of travel speed and protective gas mixture parameters in a design of experiments (DOE) could provide a source of information of practical industrial value.

The purpose of this research is to evaluate the travel speed and shielding gas mixtures in the GTAW process, and analyze their influence on weld penetration and the mechanical properties of 304L stainless steel tubing.

2. Experimental Procedure

2.1 Preparation.

In order to identify the initial microstructure present in the base metal before being welded by GTAW process, 12 mm diameter 304L pipe coupons were polished to obtain a metallographic surface, etching was performed using reagent Marble's during a period of 20 to 25 seconds to reveal microstructure. Subsequent analysis was performed by optical microscopy. For the welded GTAW coupons used the type butt joint without filler, the corresponding chemical composition of base metal was obtained by optical emission spectroscopy (OES) as shown in Table 1.

C	Si	Mn	P	S	Cr	Mo	Ni	Fe
0.028	0.38	1.64	0.024	0.015	18	0.01	8	Balance

Table 1. Chemical composition (wt%) of 304L stainless steel base metal.

A factorial multilevel DOE was considered for present research. Table 2 shows the parameters studied and their respective levels. It can be seen that gas mixture and travel speed parameters were selected as input variables in the DOE, the conditions of GTAW process with three levels in the gas mixture as a protective agent in the weld and three levels of feed rates. In order to verify the reproducibility of the nine samples were made for duplicate.

Sample	DOE	H_2 Content in Gas Mixture (%)	Travel Speed (m/h)
1B	5	0	335
2A	15	0	350
2B	9	0	365
3A	17	6	335
3B	2	6	350
4A	6	6	365
4B	10	12	335
5A	4	12	350
5B	1	12	365

Table 2. Welding parameters used in the development of experimentation.

After completing welding procedures, visual inspection of coupons was performed for the selection of representative samples (listed in Table 3). Subsequent metallographic analysis considering ASTM E 3-08 was performed. Vickers hardness testing was performed transversely to welding per ASTM E384-07 with a load of 0.5 kg. The welded coupons were cutting transversely with aim to verify of weld penetration. Welding practice on coupons was evaluated by the “reverse” test performed according to ASTM A249 "Standard specification for welded austenitic steel boiler, superheat, heat exchanger and condenser tubes”, making a bend in the welded zone with an angle of 45º. If weld does not fail during reverse testing, it is considered as a sane welding.

3. Results and discussion

3.1 Analysis of the initial microstructure.

The evaluation of the initial base metal microstructure showed the presence of the equiaxed austenitic grains with grain size of 7-8 ASTM. Some grains show presence of twins, feature that is characteristic of these steels due to its low carbon content. A representative image of this microstructure is present in Figure 1.

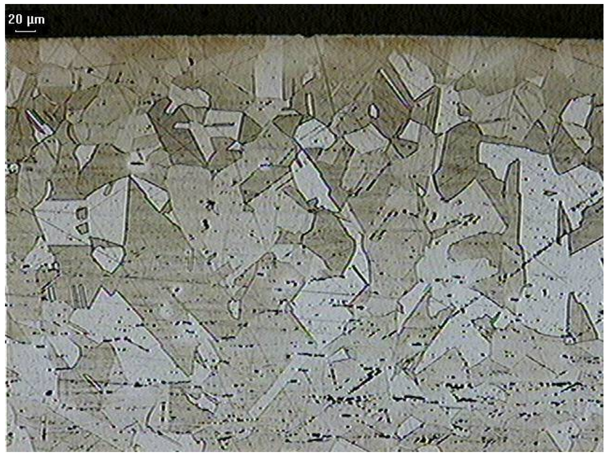

Figure 1. Microstructures at 200X.

3.2 Analysis of the welded microstructure.

Figure 2 shows representative microstructures after welding procedures with different processing parameters. Similar dendritic structures were observed in all samples without observing a significant difference with the change of welding travel speed, and H_2 content in gas mixture. However, the size of the dendrites increases with decreasing the travel speed and the increase in H_2 in the mixture. Not shown the presence of sensitization to any conditions.

Figure 2. Representative microstructures in samples welded. a) Travel speed 365 m/h and 6% H_2. b) Travel speed 350 m/h and 12% H_2. Micrographs at 200X

3.3 Penetration characteristics.

The penetration behavior of evaluated welding procedures is summarized in Figure 3. The results suggested that the highest penetration is obtained when the H_2 content in shielding gas mixture increase and the travel speed decreases. Obtained an increase of 100% of penetration in weld with 12% of H_2 or the travel speed of 335m/h. In both cases an increase in heat input, improve the penetration of the weld [5]. However with increase the 8% H_2 in the mixed is possible obtained the complete penetration even when use the high travel speed.

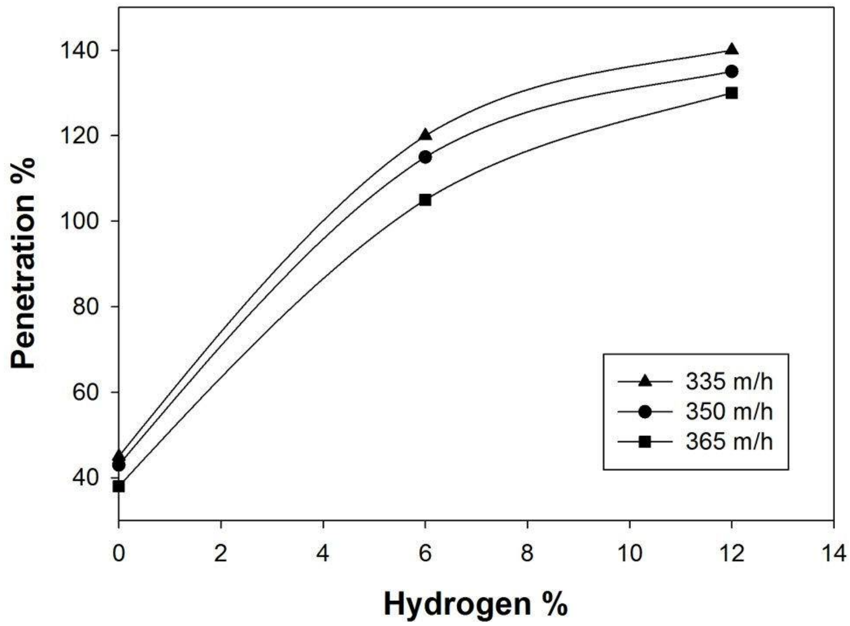

Figure 3. Relationship between penetration and hydrogen in percent for several travel speeds.

Figure 4 show the macrostructure of the developed weld penetration in the DOE. It is observed that the characteristics of the welds depend on the content of H_2 in shielding gas mixture and the travel speed. Lack of penetration in welds are typical when H_2 is absent in shielding gas mixture. When H_2 is present in quantities of 6 and 12 %, there is a complete penetration in the union of the pipe welding. The lack of penetration in the tubes affect direct in the properties and corrosion when are use in transport of liquids that is the case.

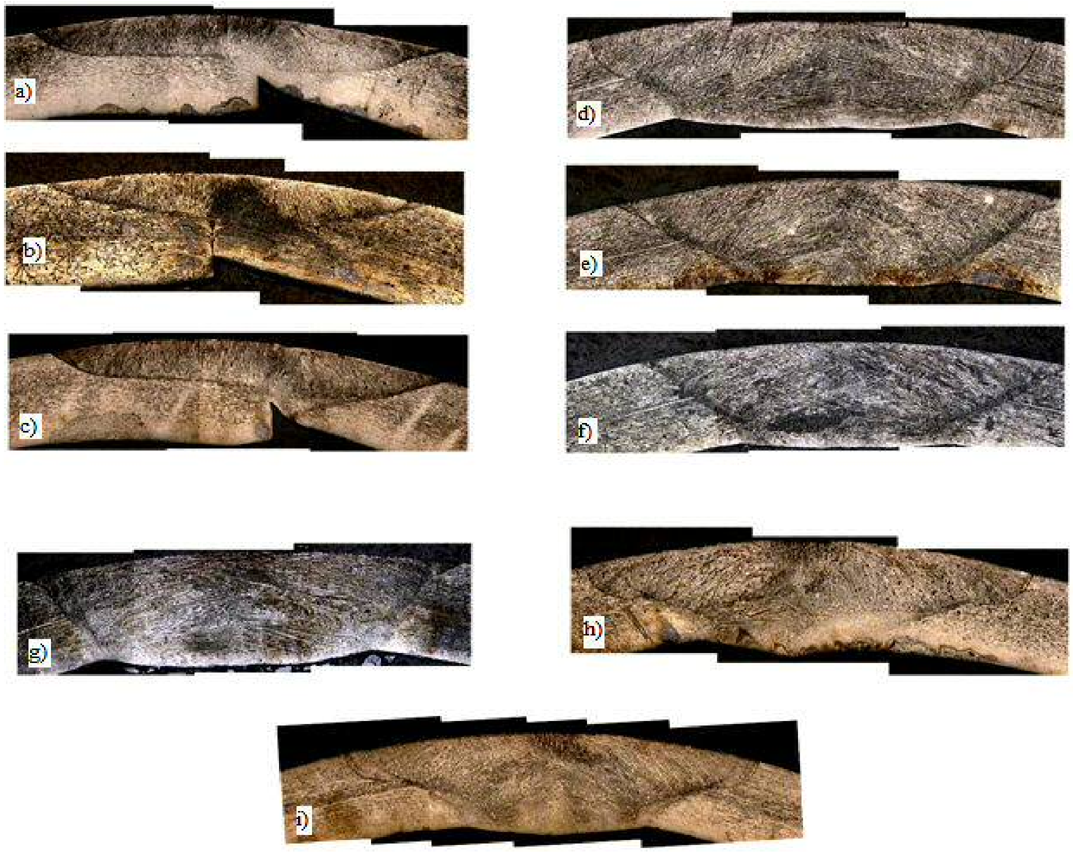

Figure 4. Metallographic profile of welded samples **a)** travel speed 335.28m/h, 0%H_2 **b)** travel speed 350.52m/h, 0%H_2 **c)** travel speed 365.76m/h, 0%H_2 **d)** travel speed 335.28m/h, 6%H_2 **e)** travel speed 350.52m/h, 6%H_2 **f)** travel speed 365.76m/h, 6%H_2 **g)** travel speed 335.28m/h, 12%H_2 **h)** travel speed 350.52m/h, 12%H_2 **i)** travel speed 365.76m/h, 12%H_2.

Figure 5 shown values obtained for the influence of H_2 content in shielding gas mixture and travel speed parameters on the welding penetration behavior considering DOE samples listed in (Table 2). Table 3 shows the statistic results obtained by MINITAB-16 software for the ANOVAs of two factors; confirm that shielding gas mixture is the most significant parameter in the welding penetration and generate an atmosphere of protection from oxidation.

The researches demonstrate the increased heat input is related to the dissociation of H_2 in the arc to form atomic hydrogen (H). The atomic hydrogen is then recombined as H_2 in the molecular form in the colder regions of the arc and on the surface of the workpiece. Presence of H_2 in the shielding gas mixture increases the surface tension of the liquid in the stainless steel because it decreases the concentration of O_2 on the surface [7-9].

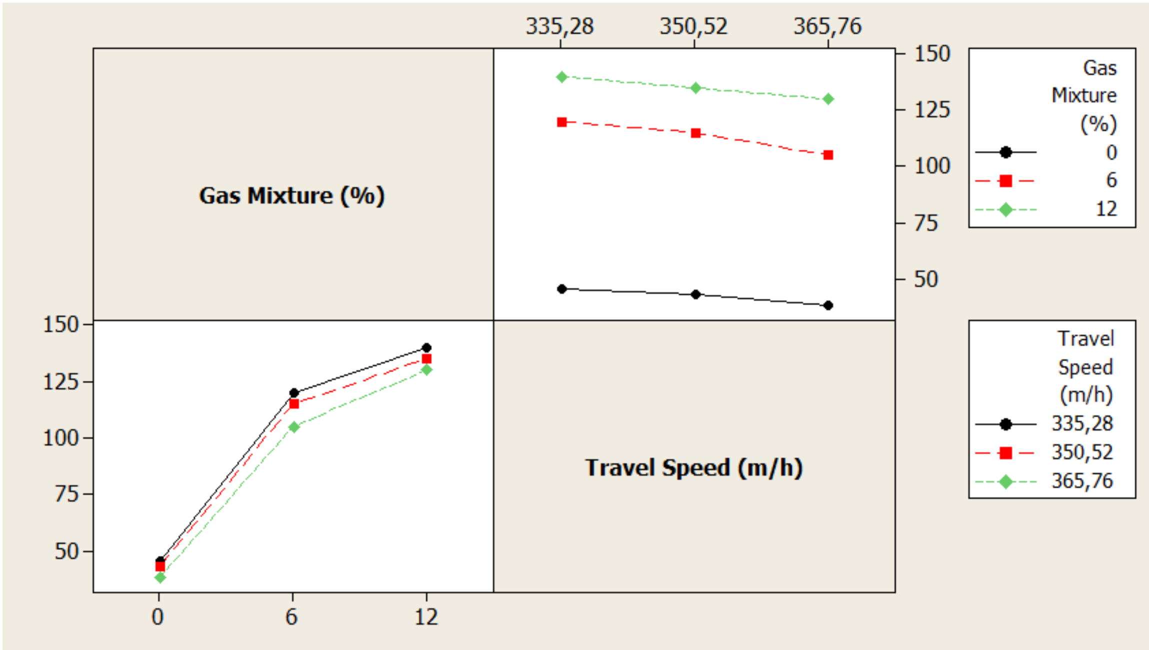

Figure 5. Plot of welding parameters and their interaction with the penetration.

ANOVAs of two factors : Penetration (%) vs Gas Mixture (%); Travel speed (m/h)

Variable	GL	SC	MC	F	P
Gas Mixture (%)	2	14206,9	7103,44	1540,51	0,000
Travel speed (m/h)	2	174,2	87,11	18,89	0,009
Error	4	18,4	4,61		
Total	8	14399,6			

S = 2,147 R-sqr. = 99,87% R-sqr.a = 99,74%

Table 3. Statistics results of DOE obtained by MINITAB-16 software.

3.4 Hardness testing

Hardness testing made at different welding coupons is shown in Figure 6. The average hardness varies between 190Hv a 160Hv and therefore it is not affected by the increase in travel speed or H_2 content in the protective gas mixture. The difference in hardness found in the samples is not significant, suggesting that the value is constant.

3.5 Reverse testing

The reverse test is affected by the penetration of the weld, so that samples showed a complete penetration were accepted in this test, the coupons had a partial penetration fail when subjected to load due to concentrated efforts by the lack of penetration results of different tests applied are shown in Table 4.

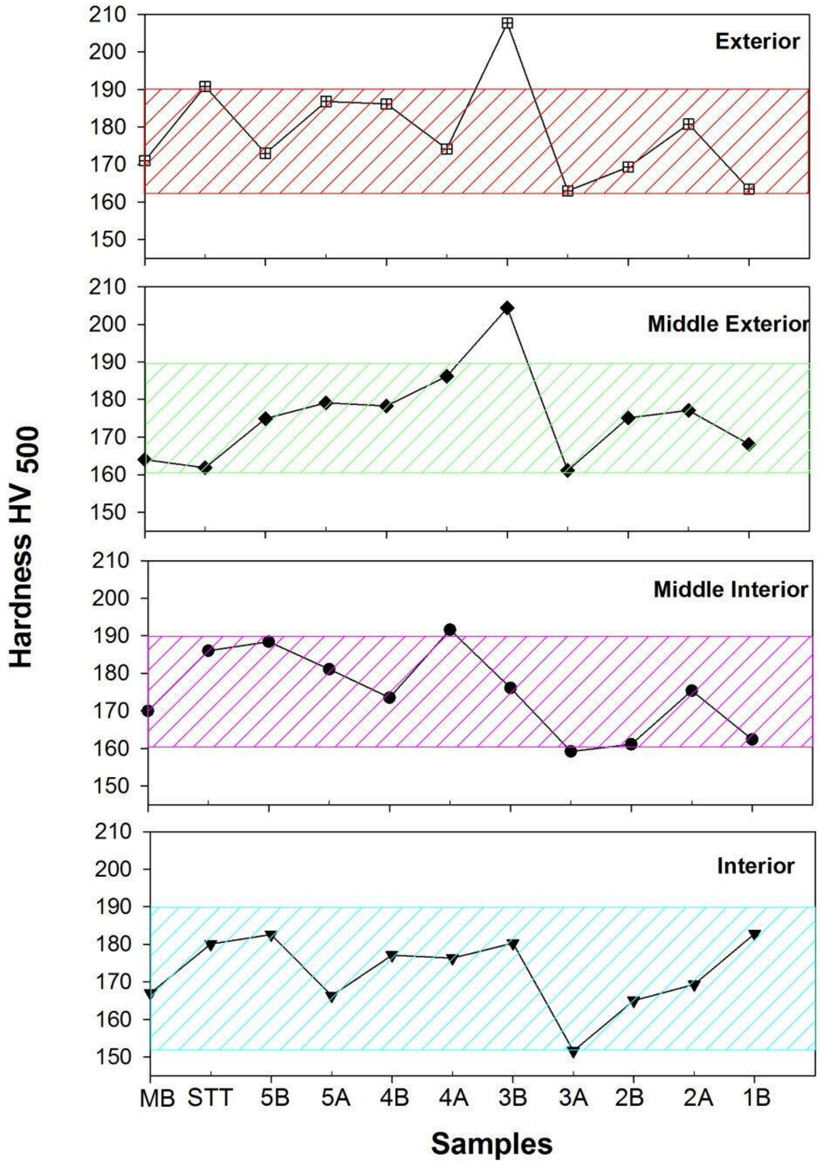

Figure 6. Vickers hardness in representative welded areas and adjacent.

Sample	DOE	Gas Mixture (%)	Travel speed (m/h)	Reverse (Go/No Go)
1B	5	0	335.28	No Go
2A	15	0	350.52	No Go
2B	9	0	365.76	No Go
3A	17	6	335.28	Go
3B	2	6	350.52	Go
4A	6	6	365.76	Go
4B	10	12	335.28	Go
5A	4	12	350.52	Go
5B	1	12	365.76	Go

Table 4. Results of reverse testing welded coupons of DOE.

4. Conclusions

According to exposed information, it can be concluded next:

- Increase of welding travel speed for GTAW process promotes lower weld penetration since a decrease in heat input is promoted.
- Presence of H_2 in protective gas mixture is necessary because it promotes an increase of the heat input.
- Hydrogen content in the mixture of over 6% ensures 100% penetration in the welded joint for the range of travel speed studied.
- Hardness is not affected by the welding travel speed or the H_2 content in protective gas mixture.
- Lack penetration in the welded samples promotes failed the reverse testing.

Acknowledgments

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