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# Kinetics of manganese in MAG/MIG welding with a 18/8/6 wire(•)

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**Abstract**

The paper deals with a study of MAG/MIG welding of low-alloy ferritic steel and high-alloy austenitic steel with a 18/8/6 wire. Manganese burn-off from the wire in welding a single-V butt weld was studied. It was found that manganese burns off in the arc during melting of a droplet at the wire end, and from the weld pool during weld formation. The range of manganese burn-off depends mainly on the type of shielding gas used and the arc length, i.e., from the arc voltage. The manganese burn-off increases with an increase of the content of active gases, i.e., $CO_2$ and $O_2$, in the neutral gas, i.e., argon. It also increases with an increase in arc voltage. The longer the welding arc, the longer exposition of the filler material to the welding arc and the wider the penetration, which allows manganese vapours to evaporate from the weld pool. The most important finding is that manganese burn-off from the 18/8/6 wire during welding of austenitic stainless steel with low-alloy ferritic steel is considerably strong, i.e., from 20% to 30%; nevertheless the wire concerned is perfectly suitable for welding of different types of steel.

**Keywords** MAG/MIG welding. Manganese. Shielding gas. Burn-off. Black-white welding.

## Cinética del manganeso en la soldadura MAG/MIG con el alambre '18/8/6'

**Resumen**

El artículo describe el estudio de un acero ferrítico poco aleado con un acero austenítico altamente aleado con el alambre 18/8/6 mediante el procedimiento MAG/MIG. Se ha investigado el consumo del manganeso del alambre durante la soldadura a tope con la preparación en V. Con los análisis se ha comprobado que el manganeso se consume en el arco desde la formación de la gota en la punta del alambre hasta la solidificación del metal aportado fundido. La cantidad perdida del manganeso depende, sobre todo, del tipo del gas de protección y de la longitud del arco, esto es, de la tensión convencional en el arco. Con el aumento de los gases activos ( $CO_2$ y $O_2$ ) respecto al gas neutro argon, el consumo del manganeso va aumentando. También se observó que el consumo del manganeso va aumentando con el incremento de la tensión convencional del arco. Mayor longitud en el arco, supone más tiempo de exposición al arco en estado fundido del material de aportación y también la penetración es más ancha, lo que aumenta la evaporación del vapor del manganeso del metal fundido del alambre. En el artículo se ha hecho también un análisis de las medidas de la dureza a través de la unión soldada. Se ha comprobado que la dureza no había aumentado en el metal fundido y que tampoco se obtuvieron estructuras martensíticas en la zona térmicamente afectada. La más importante conclusión del análisis es que el consumo del manganeso del alambre 18/8/6 durante el soldeo del acero inoxidable austenítico con acero ferrítico poco aleado es bastante alto, del 20 % al 30 %, sin embargo, este alambre es excelente para la soldadura de varios tipos de acero.

**Palabras clave** Soldadura MAG/MIG. Manganeso. Gas de protección. Consumo. Soldeo blanco-negro.

## 1. INTRODUCTION

Arc welding with a thin wire in active shielding gases, i.e., $CO_2$ and $O_2$, neutral ones, i.e., Ar and He, and their mixtures is called Metal Active Gas/Metal Inert Gas (MAG/MIG) welding. With many applications this process substituted for manual metal-arc welding with a covered electrode. In MAG/MIG welding, a thin solid or flux-cored endless wire wound on a spool is used. During welding the wire is fed through an integrated cable and a contact tube to the welding

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spot. In the arc and the weld pool, it melts and mixes with the parent metal. In spite of the fact that MAG/MIG welding is mainly used for welding of low-alloy and micro-alloyed structural steels, it is at present used for welding of almost all types of steel and a number of non-ferrous metals.

The filler material generally designed 18/8/6 contains approximately 18 % Cr, 8 % Ni and 6 % Mn. It is used for welding of different types of steel with each other and for welding of poorly weldable materials. Its manufacturers recommend it mainly for black-white welding, e.g. for welding of high-alloy stainless steel with low-alloy rusting steel.

A decisive role in terms of suitability of the 18/8/6 filler material for black-white welding plays manganese, which increases weld toughness, reduces the risk of hot-crack formation, acts as an austenitizator and deoxidises the weld metal. In deoxidisation, manganese combines with oxygen in the weld pool, forms slag, which as a very thin layer covers the weld after welding. In this process some of manganese becomes lost. This is to say that all of the manganese found in the filler material does not pass into the weld pool. This phenomenon is called manganese burn-off. The range of manganese burn-off depends mainly on the type of shielding gas, in which the arc is burning and the wire is melting, and the arc voltage.

## 2. LITERATURE REVIEW

In our literature review we came across manganese in arc welding treated from four different aspects. First, there is manganese in the parent metal. This concerned weldability of manganese steels. Secondly, there was manganese in the filler material for welding and its burn-off during melting in the arc and solidification in the weld pool. Thirdly, there is manganese in the welding flux for submerged-arc welding, which, during welding, diffuses into the weld pool. This is called manganese pick-up. Fourthly, there is manganese in welding fumes, where it is found mainly as manganese oxide.

Some basic metallurgical reactions of manganese during welding are treated[1-8]. The authors[1-4]state that the majority of manganese burns off in welding with a consumable electrode already during droplet formation at the wire end. For example, in 0.4 seconds the manganese content in the droplet at the wire end decreased from 2% to 0.65%. In the case of welding with a little lower current intensity, in the same time the manganese content in the droplet decreased from 1.4 % to 0.75 %.

Thier[5] describes a new metallurgical model for calculation of the chemical composition of the deposited metal. The model does not treat the elements concerned separately. On the contrary, it treats them all in the same way, which is certainly its weakness since it is known that all the elements do not behave in the same way but differently under different conditions or under the same conditions.

It has already been mentioned that the shielding medium exerts an important influence on the range of manganese burn-off in arc welding. Welding parameters too, particularly arc voltage, strongly affect burn-off of elements and, consequently, the chemical composition of the deposited metal. With a longer arc, the filler material is exposed to heating for a longer time, which permits burn-off of manganese and other elements. The welding parameters also strongly influence the mode of material transfer through the arc. This is to say that the size of droplets and the mode of droplet transfer from the wire to the weld pool influence the composition of the deposited metal. Although several authors[9 y 10] treat this issue, no article treating the influence of the mode of material transfer on manganese burn-off could be found. Manganese burn-off in gas shielded (Ar, $CO_2$) arc welding is treated in detail by Peprica[11], Probst and Meyendorf[12] as well as Prasad Rao and co-authors[13]. Peprica[11] found that manganese burn-off in argon shielded arc welding depended on the temperature at which the process was going on, the time of droplet formation at the wire end, and the time of droplet transfer through the arc.

Probst and Meyendorf[12] report on manganese reactions in arc welding in a gas mixture of 20 % $CO_2$ and 80 % Ar. They found that at the droplet at the wire end slag containing up to 20 % manganese formed although the wire itself was alloyed only with 2.4 % manganese. They also found that due to slag formation at the droplet, the latter lost more than 50 % manganese. They finally state that in gas shielded arc welding the composition of the gas mixture used is very important.

Prasado Rao and co-authors[13] treat manganese behaviour in $CO_2$ welding of micro-alloyed C-Mn steel with two different wires. The first contained 1.5 and the second only 1.14 wt. % of manganese. The first wire gave a deposited metal with a manganese content of 1.02 to 1.12 wt. % and the second that of 0.82 to 0.84 wt. %. This is to say that manganese burn-off amounted to 25 % to 32 %.

A greater number of authors treated kinetics of manganese in submerged arc welding than that in gas shielded arc welding. In submerged arc welding, chemical and metallurgical reactions are much more lively than in gas shielded arc welding. In submerged arc welding not only burn-off but also pick-up of elements from the flux occurs. These reactions are treated in a number of papers[14-17 y 23].

It has been mentioned that manganese plays an important role as an alloying element in the parent metal. This not being the subject of the paper, only a few papers on the subject[18-20] will be mentioned.

Almost the same is true of the fourth aspect of manganese, i.e., manganese content in welding fumes. Manganese burn-off in fusion welding indicates that manganese combined with oxygen and remained in slag or it can be found in welding fumes[21].

At present, when flux-cored wires, as well as self-shielded wires, are increasingly used in gas shielded welding, submerged arc welding, and self-shielded welding, the role of manganese is even more important than in welding with solid wires in various shielding media[22].

## 3. POSING THE PROBLEM

As already mentioned, manganese is an alloying element in steel, which exerts an important influence on the properties of the welded joint. The literature review showed that the most extensive investigations were conducted with reference to submerged arc welding. With other arc welding processes, many questions are still open, e.g. what is the influence of the composition of the shielding gas used on manganese burn-off in MIG/MAG welding, of the welding parameters, particularly of the arc length, on manganese burn-off from the filler material, during melting, and during droplet transfer through the arc. There are very intricate questions, i.e., what manganese burn-off from the weld pool and manganese diffusion from the weld metal to the parent metal are like and vice versa.

Our studies focused primarily on manganese burn-off from the 18/8/6 wire, i.e., the one containing approximately 18 % Cr, 8 % Ni, and 6 % Mn. In practice this wire is intended for welding of different types of steel, mainly of low-alloy steel with high-alloy stainless steel.

## 4. BASIC PROPERTIES OF MANGANESE

Manganese is a silvery-grey hard and brittle metal. At room temperature, it does not react with gases, but at an elevated temperature, its reaction with oxygen, sulphur and phosphorus is quite lively. Manganese has five allotropic modifications in a temperature range from room temperature to the melting point. It is most important in iron alloys and also alloyed with other metals. Steels containing more than 12 % manganese are austenitic because manganese forms austenite and stabilises it. In steel it reduces the critical cooling rate, which, in turn, increases strength, yield stress and toughness. Manganese compounds with oxygen are MnO, $Mn_2O_3$, and $MnO_2$.

## 5. EXPERIMENTAL PROCEDURE

The experimental work was carried out under as real as possible conditions. This is to say that welding was performed with a conventional MAG/MIG current source with a horizontal static characteristics. The parent metals were workpieces made of different steels, i.e., low-alloy ferritic steel and high-alloy austenitic stainless steel. The filler material used was designated 18/8/6. Their chemical compositions are given in table 1.

The arc and the weld pool were protected by a gas mixture of argon and oxygen, i.e., 98% Ar + 2% $O_2$, pure carbon dioxide, and pure argon. To ensure welding-process stability, welding was carried out automatically with a welding speed of 0.4 m/min. A single-V butt weld was welded (Fig. 1).

Special experiments were made in order to determine manganese burn-off from the droplet formed at the wire end and travelling through the arc. Figure 2 schematically shows a device for MAG/MIG welding with the 18/8/6 wire on a water-cooled copper plate. The welding parameters used ensured free flight of droplets through the arc, i.e., without a short circuit between the wire and the workpiece. The same parameters ensuring a quality-made welded joint were used for black-white welding.

The range of manganese burn-off in the arc was determined with a chemical analysis of the droplets solidified and cooled on the water-cooled workpiece (Fig. 2). The conventional wet technique of a chemical analysis was used.

Macro sections for a further analysis were made of the welded joints which satisfied the stringent

**Table I.** Designations and chemical compositions of the parent metals and the filler material for welding

*Tabla I. Designación y composición química de los materiales base y de aportación*

| Material designation | Material description | C | Si | Mn | P | S | Cr | Ni | Ti |
|---|---|---|---|---|---|---|---|---|---|
| W 1 | Low-alloy steel | 0.20 | 0.40 | 0.60 | 0.05 | 0.05 | / | / | / |
| W 2 | Stainless austenitic steel | 0.10 | 1.0 | 2.0 | 0.03 | 0.02 | 18.0 | 10.0 | 0.8 |
| 18/8/6 | Filler material - 1.2 mm wire | 0.12 | 0.6 | 6.89 | 0.03 | 0.02 | 19.3 | 8.82 | / |

criteria of quality assessment and acceptability. A chemical analysis to determine manganese content and, consequently, manganese burn-off in the weld pool itself was made at five spots. In addition to the chemical analysis, hardness was measured on a line through the weld. It is hardness which is a criterion indicating that there are no martensitic zones in the welded joint. Manganese promotes formation of the austenitic structure. It is satisfactory to assess the suitability of the 18/8/6 wire for black-and-white welding.

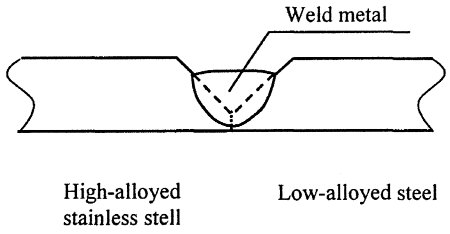

**Figure 1.** Schematic of single-V butt weld.

*Figura 1. Esquema de la soldadura a tope V.*

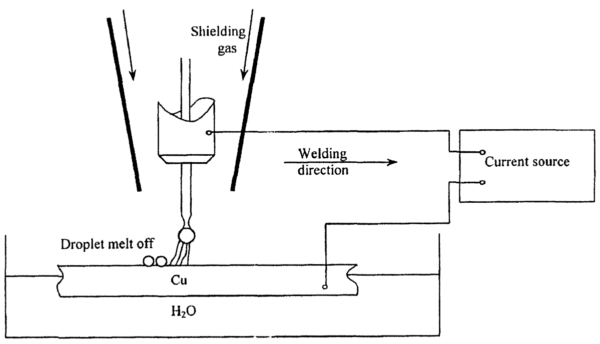

**Figure 2.** Schematic of the device for MAG/MIG welding with the 18/8/6 wire on water-cooled copper plate for an analysis of manganese burn-off in welding arc.

*Figura 2. Esquema de la instalación para soldar mediante procedimiento MAG/MIG con el alambre '18/8/6' en el plato de cobre con refrigeración mediante agua para el análisis del consumo del manganeso en el soldeo por arco.*

## 6. ANALYSIS OF TEST RESULTS

In the experiments made, solidified droplets were obtained. They were chemically analysed. From the welded joints, macro specimens were made and chemically analysed at five spots. Hardness was measured through the joint.

### 6.1. Manganese burn-off

During welding, manganese burns off in two phases, i.e., at two locations.

In the first phase, manganese burns off at the wire end when a droplet is being formed during arc burning. The longer the droplet is exposed to the arc, the more manganese burns off. That is to say that with a longer arc, i.e., in welding with a higher arc voltage, more manganese burns off than with a shorter one. Secondly, an important influence on manganese burn-off is exerted by the shielding gas used. The least manganese burns off in welding in a neutral shielding gas. The amount of manganese burnt-off increases with an increase in the portion of an oxidising gas such as $CO_2$ and $O_2$ in the shielding gas. Figure 3 schematically shows manganese burn-off at the wire end. Manganese combines with oxygen to form an oxide found at the droplet surface. This manganese oxide then travels into the weld pool and floats on its surface. After solidification, it forms a thin layer of slag over the weld.

Figure 4 shows a diagram showing manganese burn-off from the droplet in the arc during welding as a function of the arc length, i.e., arc voltage. Welding was carried out with three different gases and gas mixtures respectively but with the same other welding parameters. The experimental procedure is described in section 5 (see figures 2 and 3). The chemical analysis of the droplet was performed in the conventional wet technique and on five specimens, i.e., five droplets, obtained under the same conditions. This is to say that the

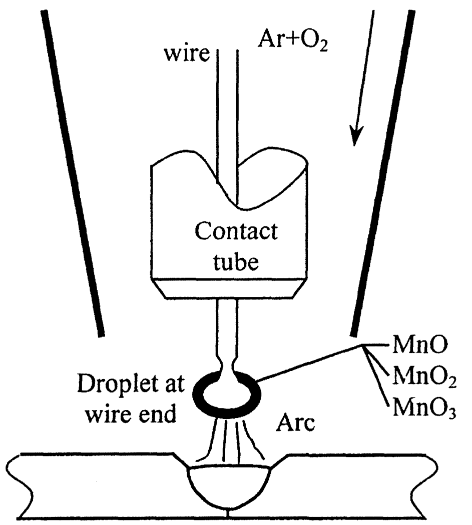

**Figure 3.** Schematic representation of formation of manganese oxide at the droplet during gas shielded arc welding in $Ar+O_2$ or $Ar+CO_2$.

*Figura 3. Esquema de la formación del óxido del manganeso en la gota durante el soldeo por arco bajo protección gaseosa ($Ar + O_2$) o ($Ar + CO_2$).*

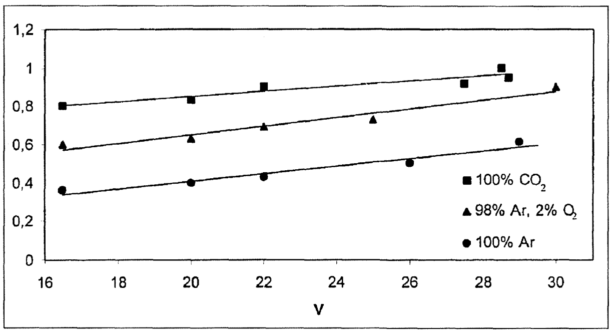

**Figure 4.** Influence of arc voltage on manganese burn-off in the arc in MAG/MIG welding in different gas mixtures ($I$ = 175 A, $v_v$ = 0.4 m/min, $d_w$ = 1.2 mm).

*Figura 4. Influencia de la tensión convencional del arco sobre el consumo del manganeso en el arco con la soldadura MAG/MIG con diferentes mezclas de gases de protección ($I$ = 175 A , $v_v$ = 0,4 m/min, $d_w$ = 1,2 mm).*

diagram in figure 4 shows statistical values. The diagram shows that the most of managanese oxidized in welding in pure $CO_2$, a little less in welding in the Ar+2 % $O_2$ mixture, and the least in welding in pure argon.

It was also found that with an increase in the arc voltage, the burn-off of managanese increased linearly.

In addition to manganese burn-off, burn-off of chromium and nickel were studied too. Although chromium is a highly oxidising element, its burn-off was much weaker than that of manganese. Chromium burn-off was from 0.2 to 0.4 %, and nickel burn-off from 0.1 to 0.3 %.

The other location of manganese burn-off in MAG/MIG welding with a consumable electrode was the weld pool. In addition to oxidation, manganese burns off also by evaporation, which occurs mostly in the weld pool.

An increase in temperature produces an increase in partial vapour pressure of all alloying elements. When partial pressure reaches the value equal to atmospheric pressure of 1 bar, a substance boils. Figure 5 shows saturation pressure of manganese as a function of temperature.

Variation of vapour pressure of manganese indicates that in welding with an unshielded arc manganese burn-off is strong. With a weld pool heated up to 2000 to 2300 °C, total vapour pressure $p_o$ is made up of several components so that it can be defined

$$p_o = p_1 y_1 + p_2 y_2 + \ldots + p_i y_i \qquad (1)$$

where $y_i$ is the molecule fraction of components i, and $p_i$ is the partial vapour pressure of components i at a given temperature. Calculations in accordance with Eq. (1) show that vapours of steel containing 1.04 % Mn and 0.8 % Si and heated up to 2500 °C will contain more than 20 % Mn. This is to say that in welding with the unshielded arc considerable losses of manganese may occur due to evaporation.

The oxidising conditions have an important influence on the evaporation of manganese. The manganese vapours generated during welding

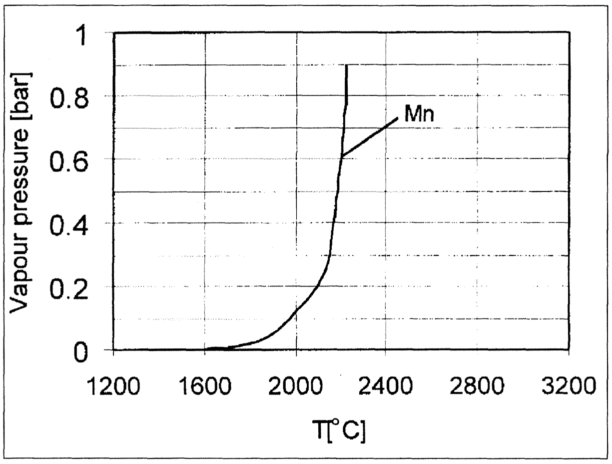

**Figure 5.** Vapour pressure of manganese as a function of temperature.

*Figura 5. Presión vapor del manganeso en dependencia con la temperatura.*

oxidize very quickly, and are transferred partly into fume and partly into slag. How much manganese will oxidize in this way depends on the composition of the shielding-gas mixture used. The curve in figure 6 referring to welding with an electrode wire with 0.2 % C, 1.2 % Si, 0.95 % Mn and 1 % Cr in argon confirms this statement.

A coefficient of manganese transfer from the wire, i.e., the filler material, to the weld pool is defined

$$\eta = \frac{Mn_{weld}\,[\%]}{Mn_{wire}\,[\%]} \qquad (2)$$

Coefficient $\eta$ always has the positive sign. In welding with the open arc it is less than 1 whereas in submerged arc welding, where manganese is transferred from the flux to the weld metal, i.e., manganese pick-up, it is higher than 1.

## 6.2. Chemical analysis of the welded joint

At the macro specimens made, chemical analyses were made of all the parts of welded joint, i.e., of both parent metals, both heat-affected zones, and the deposited metal. A purpose of the chemical analysis was primarily to determine the amount of manganese in individual parts of the welded joint and, consequently, the range of manganese burn-off during welding. Figure 7 schematically shows a macro specimen and the spots at which chemical analyses were made. The chemical analysis of the heat-affected zone was to show eventual manganese diffusion from the weld pool to the parent metal.

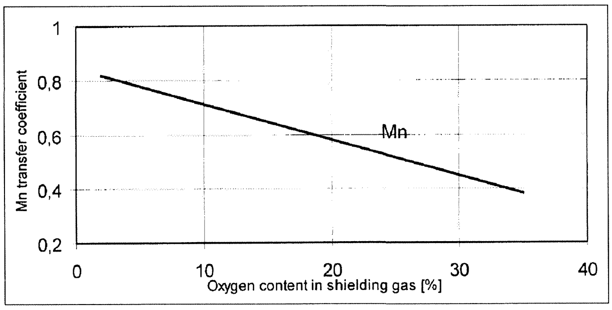

**Figure 6.** Influence of oxygen concentration in argon on the quantity of manganese transfer from filler material to weld metal (wire: 0.2 % C, 1.2 % Si, 0.95 % Mn, 1.0 % Cr).

*Figura 6. Influencia de la concentración del oxígeno en el gas argono sobre la cantidad del tránsito desde el material aportado al metal fundido (alambre: 0,2 % C, 1,2 % Si, 0,95 % Mn, 1,0 % Cr).*

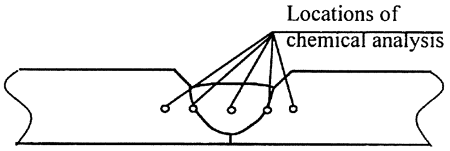

**Figure 7.** Schematic of macro specimen showing spots at which chemical analysis was made.

*Figura 7. Esquema de la probeta macrográfica con los puntos señalados, sobre los que fue hecho el análisis químico.*

Figure 8 shows a macro specimen of a joint of low-alloy steel and high-alloy steel which was MAG/MIG welded with the 18/8/6 wire. The welding parameters are given below the figure.

Figure 9 shows variation of manganese content in the welded joint as a whole. The welded joint was welded with the parameters given below the figure. In addition to manganese, also chromium and nickel contents were measured at the spots shown in figure 7. Manganese content was measured in the welds made with different welding parameters. Studies showed that welding current intensity has practically no influence on manganese burn-off whereas with an increase in arc voltage, manganese burn-off increases too.

Figure 10 shows the influence of arc voltage on manganese burn-off during welding with the 18/8/6 wire in different shielding gas mixtures but with the same welding parameters. As already mentioned, a higher arc voltage produces a longer welding arc. Consequently, the molten filler material is exposed to the arc for a longer time, which results in a stronger manganese burn-off.

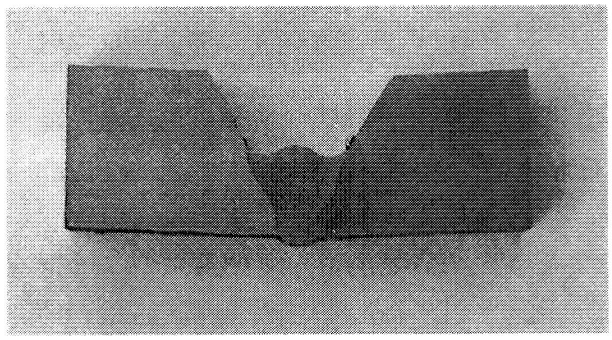

**Figure 8.** Macro specimen of a black-white welded joint ($I$ = 175 A, $U$ = 20 V, $v_v$ = 0.4 m/min, gas flow rate of Ar+2%$O_2$ = 10 l/min, wire = 1.2 mm (18/8/6)).

*Figura 8. Probeta macrográfica 'blanco – negro' de la unión soldada ($I$ = 175 A, $U$ = 20 V, $v_v$ = 0,4 m/min, caudal del gas Ar + 2 % $O_2$ = 10 l/min, alambre = 1,2 mm (18/8/6)).*

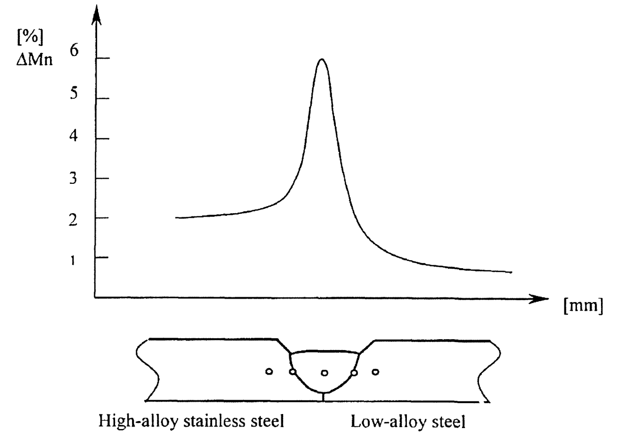

**Figure 9.** Variation of manganese content in welded joint as a whole.

*Figura 9. Variación del contenido del manganeso en la unión soldada.*

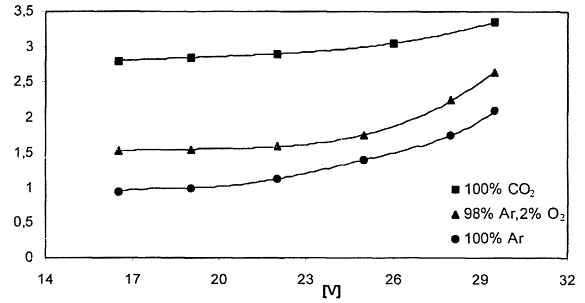

**Figure 10.** Influence of arc voltage on manganese burn-off in MAG/MIG welding with different gases and gas mixtures respectively ($I$ = 175 A, $v_v$ = 0.4 m/min, $d_w$ = 1.2 mm 18/8/6).

*Figura 10. Influencia de la tensión sobre el consumo del manganeso en la soldadura MAG/MIG para, en diferentes mezclas de gases ($I$ = 175 A, $v_v$ = 0,4 m/min, $d_w$ = 1,2 mm (18/8/6)).*

With a higher arc voltage, also a wider weld surface is obtained after welding. That is to say that during welding there are certain conditions favouring manganese evaporation from the weld pool. As already stated, welding fumes contain manganese too.

It was also found that with an increase in arc voltage, manganese burn-off during welding in pure carbon dioxide increases more slowly but more intensely than in welding in argon, which is a neutral gas. This is explained by the fact that in $CO_2$ welding larger droplets melt off and that there are less favourable conditions for manganese burn-off (see figures 3 and 4). Moreover in welding with the 18/8/6 wire a considerable amount of chromium burns off, which, to a certain extent, prevents manganese burn-off since chromium combines with excessive oxygen.

Regardless of the data stated in the diagram in figure 10, it is recommended to use the 98 %Ar+2%$O_2$ gas mixture as a shielding gas. With this mixture, namely, the droplet-melting process and the weld-pool movement are more stable than with the pure gases (Ar or $CO_2$).

### 6.3. Hardness measurement in the black-and-white welded joint

Hardness measurement was to indicate mechanical properties of the welded joint, the steel structure (martensite or austenite), and manganese burn-off. Figure 11 shows through-weld hardness variation. It can be observed that hardness slightly increases in the heat-affected zone of low-alloy steel. This is explained by a partial dilution in the zone - see Schaeffler diagram - which produces the martensitic structure and, consequently, higher hardness. Because of a low energy input during welding no through-hardening occurred and, consequently, hardness did not exceed 240 HV. That is to say in the weld metal there is manganese enough to form the austenitic structure.

Hardness increased slightly also in the weld itself but this had no particular influence on mechanical properties, particularly toughness.

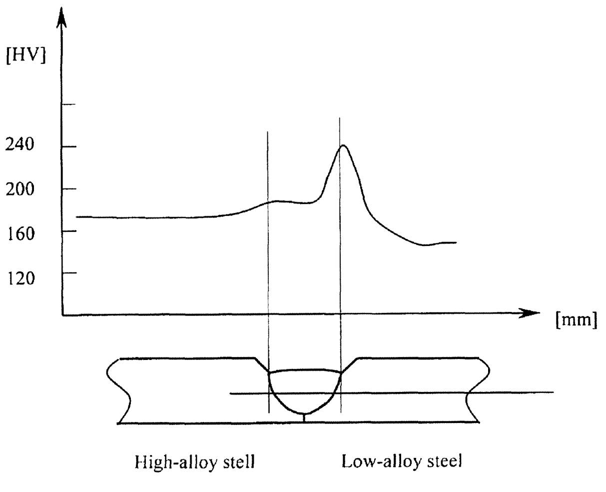

**Figure 11.** Variation of hardness in black-white weld made with the 18/8/6 wire (98 % Ar + 2 % $O_2$, $I$ = 185 A, $U$ = 22 V, $v_v$ = 0.4 m/min, $d_w$ = 1.2 mm).

*Figura 11. Variación de la dureza a través del metal fundido en el soldeo del alambre "18/8/6" (gas de proteción 98 % Ar + 2 $O^2$, $I$ = 185 A, $U$ = 22 V, $d_w$ = 1,2 mm, $v_v$ = 0,4 m/min).*

## 7. CONCLUSIONS

On the basis of the research of the kinetics of manganese in MAG/MIG welding with the 18/8/6 wire, the following conclusions can be drawn:

- During arc welding, manganese burns off from the wire tip heated to the melting temperature by the arc and from the weld pool.
- The size of manganese burn-off depends on the arc voltage and the composition of the shielding gas used.
- The other welding parameters such as welding current, the welding speed, and the kind of current exert almost no influence on the size of manganese burn-off.
- The manganese burn-off is affected also by the composition of the welding wire. If the wire contains at least 10 % chrome, the manganese burn-off is less.
- For MAG/MIG welding the 98 % Ar + 2 % $O_2$ gas mixture is recommended as a shielding gas. The addition of 2 % $O_2$ actually increases the manganese burn-off but it also stabilises the melting-off of the droplets from the wire and, consequently, affects the stability of the entire process.
- The entire manganese burn-off from the 18/8/6 wire containing 6.9 % Mn amounts to around 1.6 % with an arc voltage of 21 V and with the 98 % Ar + 2 % $O_2$ gas mixture.
- In spite of manganese burn-off, the 18/8/6 wire is well suitable for welding poorly weldable steels and of different steels, i.e., the so-called black-and-white welding.

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