Effect of Shielding Gases on Austenitic Stainless Steel Overlay by FCAW Process on Low Alloy Steel

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Abstract: ***Pressure vessels and high pressure heat exchangers used for chemical, petrochemical and refineries are normally fabricated from creep resistant low alloy steel material. The internal surfaces of these equipments are given a surface treatment (cladding) using austenitic stainless steel in order to prevent the low alloy steel from aggressive corrosion effects of the process fluids. Small diameter process nozzles and other components are normally weld overlaid using flux cored arc welding process; pure CO_2 is used as a shielding gas. Nowadays, stringent requirements are being enforced by many customers/process licensors on restricting the use of 100% CO_2 as shielding gas for FCAW process. This necessitates development of stainless steel FCAW weld overlay procedures employing various shielding gases/mixtures. The current study involves the use of flux cored arc welding (FCAW) process to deposit austenitic stainless steel (Type 347) overlay on low alloy steel (1 ¼ Cr – ½ Mo) .Cladding was performed by depositing a barrier layer of type 309L stainless steel and one layer of type 347 stainless steel over the barrier layer. In the first phase of experiment two different shielding gases were employed: pure Ar, and pure CO_2. Samples from various overlay coupons were subjected to macroscopic examination for studying bead characteristics and microscopic examination for studying ferrite phase distribution and inclusions. Chemical analysis using spectroscopic method was also carried out with intent to understand, in detail, the effect on carbon content due to nature of reactions it undergoes with the shielding gas and flux of the cored-wire. Ferrite survey, using Feritescope and bend ductility tests were also carried out.***

Keywords: Shielding gas properties, Stainless steel weld overlay requirements, carbon content, dilution, and the Role of SiO_2 content of flux

1. Introduction

In chemical and petrochemical industries, it is difficult to resist the effect of highly corrosive atmosphere of hydrocarbons on the low alloy steel pressure vessels or heat exchangers. Stainless steel is a corrosion resistant material, but it is very costly. So, by applying SS-Lining/cladding on the inner surface of Carbon/ Low alloy steel vessels economically serve both the purpose – required mechanical properties and good corrosion resistance properties. The internal surfaces of the high pressure heat exchangers are given a surface treatment using austenitic stainless steel in order to prevent the low alloy steel from aggressive corrosion effects of the process fluids. The shape of the component and its accessibility influences, the position in which cladding can be carried out. Whenever possible, surfacing is carried out in the flat position using a high deposition rate process. Complex shapes and difficult access will likewise restrict the choice of process to the single arc systems, like GMAW, FCAW etc. [1].

Flux cored wires are aimed to combine the advantages of the flux of manual metal arc electrodes with the continuous welding capability of solid wires. FCAW employs a tubular wire electrode whose core contains: a) Alloying materials which can be tailored to meet the deposit chemistry and corrosion/ wear requirements, b) Fluxing agents to improve wetting and deposit appearance c) Fluxes to generate gas shield. Since the fluxes can even generate a protective gas shielding, one of the variations of the process is Self shielded FCAW process, well known as FCAW-S, where S stands for self shield property. FCAW- S is often used for onsite welding purpose like in ship building, repairs of railway tracks etc. [1]. However, for the corrosion resistant overlay purpose the gas shielded FCAW process, which is well known as FCAW-G, is preferred.

The shielding gases used for carbon manganese flux cored wires are either CO_2 or argon based mixtures containing CO_2, O_2 or both. Argon based or helium rich mixtures may be used with stainless steel wires, but in all case, if the optimum performance and weld metal properties are required, the gas chosen should comply with the recommendations of the wire manufacturer [2].

The main features of the FCAW Process are: high deposition rates, alloying addition from the flux core, slag shielding and support and improved arc stabilization and gas shielding [2]. The shielding gas and flow rate have a pronounced effect on the following: arc characteristics, mode of metal transfer, penetration and weld bead profile, speed of welding, undercutting tendency, cleaning action, weld metal mechanical properties [3].

There are two basic requirements for the overlay: minimum dilution of the substrate material to attain the correct chemistry, 3 mm from the top of the bead, and the flat profile of the weld bead, for 50% overlap with the adjacent beads. The two main variables which affect the properties of the deposited metal when FCAW process is employed are the flux composition of the wire and the shielding gas used [4].

Different gases have different effects, depending on its properties especially at arc temperatures. Thermal conductivity, surface tension of the molten metal in a particular shielding gas atmosphere and oxidation potential are the main properties of the shielding gas which affects the chemistry and the bead profile of the deposited material.

For the stainless steel overlay pure CO_2 and Ar – CO_2 gas blends are usually employed to provide shielding, with flux cored wires. The effects of the thermal conductivity, surface tension and oxidation properties of Pure CO_2 and Pure Ar gases on the stainless steel overlay by FCAW-G process are as follows:

2. Effect of Thermal Conductivity

Argon atoms are easily ionized at the arc, which results in a highly charged path between the electrode and work piece. This concentration of energy constricts the droplet size of the weld metal, thus keeping transfer well within the spray mode. Pure Ar due to the low thermal conductivity and higher surface tension has low penetration compared to pure CO_2 and produces an arc transfer which is difficult to control. CO_2 has higher thermal conductivity and low surface tension has dipper and wider penetration than 100% Ar. It is also reported that there is higher base metal dilution with the filler metal, in the CO_2 containing shielding gas atmosphere as compared to pure Ar, (The effect from process parameters on dilution is restricted by maintaining the same parameters for both the types of gases/mixtures). Figure 1, illustrates the effect of thermal conductivity and surface tension on the weld bead profile.

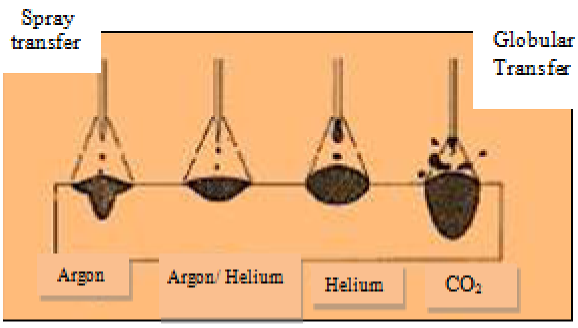

Figure 1: Effect of thermal conductivity on metal transfer and bead profile

3. Effect of Oxidation Potential in the Shielding Gas

Oxidation potential of the shielding gas is equal to the % O_2 + ½ % CO_2 [6] .It is reported that the use of carbon dioxide containing shielding gases may result in the change in carbon content of the weld metal. During the welding of stainless steel using CO_2 containing shielding gases, two different types of reactions may take place, depending on the % C in the weld molten metal at the time of welding. These reactions are as under,

In the heat of the arc CO_2 breaks down into oxygen and carbon monoxide which prevents some alloying elements from being transferred into the weld pool resulting in loss of alloying elements.

$$2\ CO_2 \leftrightarrow 2CO + O_2 \text{ --------- \{Eq.1\}}$$

Now due to the presence of the oxygen in the weld metal during weld, some of the elements like Si, Mn, and Cr etc will be easily oxidized. Thus their levels in the deposit may be reduced. It is seen that with the decrease in Si and Mn levels, the strength and toughness of the metal gets reduced and the loss of alloying elements like Cr affects the ferrite number (decrease in ferrite number) of the weld metal. Now molten iron reacts with CO_2 and produces iron oxide and carbon monoxide in a reversible reaction:

$$Fe + CO_2 \leftrightarrow FeO + CO \text{ .... \{Eq.2\}}$$

At red heat temperatures, some of the carbon monoxide dissociates to carbon and oxygen, as follows:

$$2\ CO \leftrightarrow 2C + O_2 \text{ .... \{Eq.3\}}$$

The effect of CO_2 shielding on the carbon content of mild, low-alloy steel and stainless steel weld metal is unique (as also referred earlier). Depending on the original carbon content of the base metal and the electrode, the CO_2 atmosphere can behave either as a carburizing or decarburizing medium. Whether the carbon content of the weld metal will be increased or decreased depends on the carbon present in the electrode and the base metal.

If the carbon content of the weld metal is below approximately 0.05%, the weld pool will tend to pick up carbon from the CO_2 shielding atmosphere and this carburization reaction may raise the weld metal carbon level to about 0.08 to 0.1 %.Conversely, if the carbon content of the weld metal is greater than approximately 0.10% the weld pool may lose carbon.It is also reported that the increase in Cr and Si content there is increase in Carbon content.

It is reported that the above explained phenomenon is more prominent with solid wire welding. Now in solid wire welding (GMAW) using shielding gases, namely, 100% Ar and Ar – CO_2 gas blends, if the % C in the weld metal achieved by using each gas is measured and compared. Then the value of % C so measured for the weld metal achieved in the pure Ar atmosphere, which is an inert atmosphere, can become the basis or the reference value for comparing the weld metal % C achieved in the CO_2 containing shielding gas atmosphere (for % C content study). Since in the present study, flux cored wire is employed, the sole effect of shielding gas, on the % C in the weld metal, cannot be achieved even with 100% Ar shielding gas(which is an inert gas.). So it becomes necessary to know the contents of the flux, which will also have some effect on the weld metal composition. The rutile type FCAW wire was employed for the overlay. (Presence of High amount of TiO_2, Ca oxide, and SiO_2 reported during chemical analysis of flux). The flux contains mainly stable oxides, smooth arc promoters like TiO_2 and calcium oxides, Ferro alloys and some metallic powders.

During the analysis of the chemical compositions, particularly % C, of the overlay metal achieved by the experiment, the results of % C in 100% Ar atmosphere were discussed with ***Dr. D. J. Kotecki****. In those regards it was* *suggested by **Dr. D. J. Kotecki** that "the slag system of E309LT0-1 and of E347T0-1 is high in SiO2 in all of the commercial embodiments with which I am familiar. The SiO_2 can cause some oxidation of carbon, which may explain loss". Thus through this valuable guide lines, it was known that the flux contains high amount of SiO_2.*

The present study mainly deals with the effect of use of CO_2 containing shielding gas/ mixtures for the overlay of low carbon containing austenitic stainless steel on low alloy steel and also comparing these results when the overlay is carried out with pure Ar as shielding gas.

4. Experimental Details

In the first phase of experiments, 100% Ar and 100% CO_2 were used as shielding gas in FCAW process for overlay. 1 ¼ Cr , ½ Mo low alloy steel 18 mm thick plate (SA 387 Gr.11 Cl.2 according to ASME Section 2A) was used as a base material (substrate material) for the overlay purpose, which is also usually the material used for the various pressure vessels in petrochemical industries (material composition as indicated in Table 1).

For very high temperature applications, a stabilized grade SS347 which contains Nb or Ti as one of the element is used for the deposition in the overlay. Since Nb or Ti are more potent carbide formers than Cr, and thus they tie up carbon, minimizing the formation of Cr rich grain boundary carbides at higher temperatures. According to codes and standards for the SS overlay, the % of Nb should be eight times the % Carbon in the weld metal. So, one of the requirements for the overlay is to achieve the required % Nb at 3mm from the fusion line of the deposited material, which also depends on the % C achieved at that height.

Since the overlay is a joining of dissimilar metals, the first overlay layer or the barrier layer is done with SS 309L.SS 309L has richer alloying element contents, i.e., higher Cr and Ni contents (as indicated in the table 3rd column) compared to the filler that is to be used as the overlay material. This is done in order to avoid cracking during the welding and also in order to achieve the required chemistry of the overlay by depositing less number of layers. The compositional details for all the materials used are listed in the Table 1 and the value of the elements of importance is highlighted.

5. Procedure Details

One of the most important requirements for overlay is, achieving the required chemical properties of the deposited material at a minimum possible height. The second important factor is to achieve a proper flat bead shape when the overlay is done using FCAW process. The chemical properties of the weld metal are affected by the i) dilution of the filler wire material with the base material, and also ii) the reactions in the weld puddle with the shielding gas and the flux. The dilution is affected by the process parameters and the shielding gas type. So in order to study the sole effect of the shielding gas on mainly the chemical properties and the bead profile of the overlay the welding was carried out keeping the fixed range of process parameters for both the shielding gases(i.e. the effect of process parameters to contribute to the dilution and other factors is nullified.). Table 2 lists the process parameters used for both the shielding gases.

Table 1: Chemical composition of Base material, Barrier layer filler material and final layer filer material

Element (%)	*Base material*	*SS 309LT0-1 (1.2 mm φ)*	*SS 347T0-1 (1.2 mm φ)*
C	**0.145**	**0.025**	**0.035**
Mn	0.48	1.31	1.43
Cr	**1.42**	**23.58**	18.9
Ni	0.087	**12.29**	10.57
Mo	**0.477**	0.02	0.03
Si	0.519	0.57	0.36
Nb	0.005	-	**0.45**
Ti	0.004	-	-
V	0.002	-	-
Al	0.038	-	-
P	0.007	0.017	0.024
S	0.0008	0.006	0.012

For 100% Ar the process parameters, especially, the current, voltage, filler wire speed and contact tip to work distance were taken approximately 10% higher than for the pure CO_2. The weld bead profile requirements, namely the wetting angle of the bead with the base metal to be 120° for the overlay, was achieved only at a comparatively higher process parameters than those 100% CO_2 gas when 100% Ar was used as a shielding gas.

Table 2: Process Parameters

Parameters	*SS309LT0-1 (1.2 mm φ)*	*SS 347T0-1 (1.2 mm φ)*
Current (A)	160-185	145 – 170
Voltage (Volts)	25 – 26	25 -26
Filler wire speed	6	6
Travel speed	349	349
Contact tip to work distance	15	15
Gas flow rate	20	20

To study the effects of shielding gases on the overlay properties like bead profile(shape and depth of penetration) macro structure analysis of the cross sectional view of the overlay which will show the base metal, barrier layer depth of penetration in the base metal , final layer and the bead shape was carried out. In order to study the effects of shielding gases on the chemical properties of the weld overlay at the required height, chemical analysis was carried out using spectroscopy for measuring the values of % Cr, % Ni, % Si, % Nb at 1mm, 2mm, 3mm and 4mm from the fusion line. For the measurement of the % c which was of the prime interest Leco test was done and the carbon values at 1mm, 2mm, 3mm and 4mm was measured. Ferrite number was measured using feritescope.

Results and Discussion 1: Weld bead profile characteristics

Figures 2.1, 2.2. shows the cross sectional view at 10X magnification (macro structure) of the weld overlay, for 100% CO_2, 100% Ar respectively.

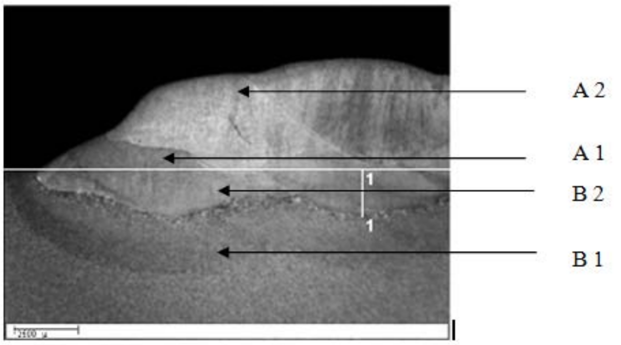

Figure 2.1 : Depth of pentration and weld bead profile of overlay trial with 100% CO_2 shielding gas (vertical white line 1-1 indicates the depth of penetration of SS 309L in the base material, horizontal white line indicates the base metal top surface) **Here, A 2 = 2.5 mm , A 1 = 1.5 mm , B 2 = depth of penetration is 1694.6 μm**

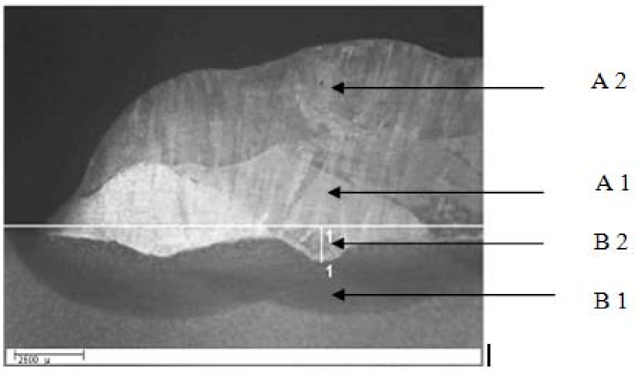

Figure 2.2: Depth of pentration and weld bead profile of overlay trial with 100% Ar shielding gas (vertical white line 1-1 indicates the depth of penetration of SS 309L in the base material, horizontal white line indicates the base metal top surface)

Here, A 2 = 4 mm , A 1 = 3.5 mm , B 2 = depth of penetration is 1181.1 μm

As discussed earlier, one of the requirements of the overlay is its flat bead profile which allows 50% overlap with the adjacent bead. This is achieved when the wetting characteristics of the depositing material on the substrate is uniform and good. The optimum wetting angle for any overlay is 120° with the base material.

1) From the above macro graphs it can be observed that the weld bead profile achieved by the CO_2 containing shielding gas/ mixture is wide, broad and has good wetting characteristics with the base metal. As the % CO_2 in the shielding gas decreases the poor wetting characteristics are observed. The bead profile achieved by 100% Ar shielding gas is having wetting angle of 100° which is quiet less than the requirement, folded bead and non uniform metal deposition.

Discussion

For welding using gas metal arc process with solid or flux cored wires, the metal transfer is highly affected by the type of shielding gas used. The bead shape is mainly influenced by the thermal conductivity of the shielding gas. The thermal conductivity of a gas is a measure of how well it is able to conduct heat. It influences the radial heat loss from the center to the periphery of the arc column as well as heat transfer between the plasma and the liquid metal. Argon, which has a low thermal conductivity, produces an arc that has two zones: a narrow hot core and a considerably cooler outer zone. The penetration profile of the weld fusion area then exhibits a narrow "finger" at the root and a wider top. Carbon dioxide has a high thermal conductivity, so it conducts heat outward from the core, this results in a wider, hotter arc core. So it gives a more even distribution of heat to the work surface and produces a wider fusion area. The folded bead characteristic(less wetting angle) of Ar rich shielding gas is, on the account of, the high surface tension of the molten metal under the Ar atmosphere.

2) From the above macro graphs it can also be seen that as the CO_2 content of the shielding gas increases the bead depth penetration increases systematically. The increased depth of penetration results in the increase in dilution, which is not favorable, as far as, particularly overlay is concerned. This was confirmed by calculations as shown in the Table 3.

Table 3: Dilution levels in barrier layer (309L) overlay as function of shielding gas

Shielding gas	*Weight % Ni*			*% Dilution*
	Base metal	*Filler metal*	*309L overlay 2mm from fusion line*	
100%CO_2	0.09	12.3	8.4	32.2
100% Ar	0.09	12.3	10.7	12.8

It may be seen from the Table 3 that, with the increase in CO_2 percentage in the shielding gas, the dilution increases systematically. This enhanced dilution % is a result of the deeper penetration accounted with CO_2 rich shielding gases.

Discussion:

1. For stainless steel oxygen is a surface active element which contributes in increasing the depth of penetration due to the positive surface tension.
2. Carbon dioxide being a multi atom molecule when heated to high temperatures within the arc plasma breaks down or dissociate, into their component atoms. As the dissociated gas comes into contact with the relatively cool work surface, the atoms recombine and release heat at that point. This heat of recombination causes CO_2 to behave as if they have a higher thermal conductivity. Thus the higher thermal conductivity of carbon dioxide (because of the dissociation and recombination of its component parts) transfers more heat to the base material than does argon alone. A broader penetration pattern versus argon is obtained.

Results and Discussion – 2: overlay chemical composition

The area of concern, when CO_2 containing shielding gases/ mixtures are employed, especially for the low carbon containing stainless steel material is that of the carbon content in the deposited weld metal. The carbon content of the overlay depends on carbon contents of the electrode filler metal, and the base metal, as also the degree of dilution. The carbon contents actually measured on the 309L at 2mm from the fusion line are listed on the Table 4 below. The table also contains the carbon contents calculated from the base and filler compositions and the dilution level. This has been done for both the shielding gases, using their respective dilution levels and these carbon levels are also included in the table.

Table 4: Comparison of measured % Carbon with calculated % carbon at 2 mm height from the fusion line for all the four shielding gases

Shielding gas	% Carbon			
	Base material	309L	Calculated from the dilution value in Table 3	Practically measured values by using Leco test
100%CO_2	0.145	0.025	0.063	0.057
100% Ar	0.145	0.025	**0.041**	0.028

The carbon content in the overlay is influenced by several factors the first is the dilution from the base metal. This basic diluted level is, however, altered due to chemical reactions that may occur between the weld pool and the slag as well as between the weld pool and the shielding gas. In FCAW the flux used contains number of oxides and the other compounds such as CaF_2 besides metallic powders such as ferroalloys. Although these oxides are generally considered stable, a few of them like SiO_2 are considered to be relatively less stable than the others. This means that oxides like SiO_2 can dissociate in the heat of the arc, releasing O_2 and increasing the oxygen potential in the welding atmosphere. It is obvious that slag metal interactions of this kind might oxidize the carbon in the weld pool and lead to decrease in the carbon content in the weld metal. [9]

With respect to the interaction of the shielding gas with the weld pool, the use of pure Ar will not involve any chemical reaction and hence not affect the carbon content in the weld. On the other hand, if the shielding gas contains CO_2, chemical reactions are possible and will involve 2 different kinds of reactions depending on the weld chemistry. The more obvious reaction is [7]

Reaction 1

"CO2 + C = 2 CO (from the weld metal) " Eq. 1

This will result in a decrease in weld metal carbon content. Second kind of reactions is also possible.

Reaction Set 2

At red hot temperature the carbon dioxide dissociates to carbon monoxide and oxygen, as in equation 2.

$$2\,CO_2 \leftrightarrow 2CO + O_2 \text{ ------ Eq.2}$$

Molten iron reacts with CO_2 and produces iron oxide and carbon monoxide in a reversible reaction:

$$Fe + CO_2 \leftrightarrow FeO + CO \text{ ------ Eq.3}$$

At arc temperature, some of the carbon monoxide dissociates to carbon and oxygen, as shown in Eq. 4

$$2CO \rightarrow 2C + O_2 \text{ ------ Eq. 4}$$

If this reaction occurs, the carbon content in the weld pool will actually increase as a result of gas metal reaction.

Whether reaction 1 + 2 occurs depends upon the basis carbon content of the weld pool. This basis carbon content is the diluted overlay carbon content when pure Ar shielding gas is used without a flux or an entirely chemically neutral flux. This would mean, for example, the diluted carbon level in solid wire GMA welding using 100% Ar. It has been found that, when this carbon level is above 0.08 to 0.1% the oxidation reaction will predominate and causes a decrease in weld pool carbon content. If on the other hand, the basis carbon content level is lower than 0.05% the CO_2 dissociation reaction will take precedence and cause an increase in carbon content in the weld metal.

In the current study, since FCAW was used and a flux was always present, this basis carbon level cannot be determined. From the table 4 it may be noted that the carbon level under 100% Ar is significantly lower than the carbon levels measured for 100% CO_2.

This level with 100% Ar, namely 0.028%, actually reflects the basis carbon level as decreased by the oxidizing action of the flux. The carbon level in the deposit, calculated from the base metal and filler metal composition and the dilution with 100% Ar, is 0.041% as seen from table 4 (last value in column 4), this is the nearest approximation to the nearest carbon content. The actual carbon% of 0.028 is decreased from this basis level because of oxidation by the flux. On the other hand the carbon level in the deposit, calculated from the base metal and filler metal composition and the dilution with 100% CO_2, is 0.063 as seen from table 4 (first value in column 4). Here too the actual carbon % of 0.057 is decreased from the basis level, but here, the reason is as explained above, i.e. the oxidation reaction (reaction type 1) due to the shielding gas when the molten metal carbon content in greater than 0.05%.

The above effects of both the shielding gases were when 309L was deposited on the low alloy steel material. Now SS347 is deposited over the barrier layer of SS 309L. To study the effect of both the shielding gases on % C of the weld metal, % C at 3mm from the fusion line was measured using LECO testing method. The result along with the similar comparison as above is shown in Table 5.

Table 5: Comparison of measured % carbon with calculated % carbon at 3mm height from the fusion line for all the four shielding gases

Shielding gas	% Carbon			
	Base material	SS347	Calculated from the dilution value in Table 3	Practically measured values by using Leco test
100% CO_2	0.057	0.035	0.042	0.0460
100% Ar	0.028	0.035	0.034	0.0270

From the table 5 it may be noted that the carbon level under 100% Ar is significantly lower than the carbon levels measured for CO_2 containing mixtures which is same as for the SS309L deposited on low alloy steel base metal.

This level with 100% Ar, namely 0.027%, actually reflects the basis carbon level as decreased by the oxidizing action of the flux.

The carbon level in the deposit, calculated from the % C (SS309L) measured at 2mm from the fusion line and SS 347 composition and the dilution with 100% Ar, is 0.034% as seen from table 5 (last value in column 4), this is the nearest approximation to the nearest carbon content. The actual carbon% of 0.027 is decreased from this basis level because of oxidation by the flux.

On the other hand the carbon level in the deposit, calculated from the % C (SS309L) measured at 2mm from the fusion line and SS 347 composition and the dilution with 100% CO_2 gas is 0.042 (value < 0.05%) as seen from table 5. Here the actual carbon % of 0.046, is increased from the basis level, due to the pickup of carbon phenomena as explained above. That is as per reaction type 2 when the weld molten metal % C is less than 0.05%, there is a carbon pick up from the shielding gas.

As explained earlier, the chemical composition of the weld overlay depends on the gas metal and the slag metal reactions occurring in the weld puddle. The effect of the shielding gases/ mixtures on the basic alloying element in the austenitic stainless steel overlay, i.e. Chromium (which is also a potent carbide former) was studied.

In the oxidizing atmosphere Cr from the weld metal can be oxidized easily and can be lost in the slag during overlay. Normally when the overlay is done using flux cored electrode this loss is compensated by the Cr present in the flux. In this study the effect of shielding gases on the chromium content was determined by comparing the calculated % Cr using the Cr contents of base material, filler material and the dilution with each gas, with the measured Cr % at 2mm from the fusion line. The calculated and measured values along with the other compositional details are listed in table 6 below.

Table 6: Comparison of measured % Cr with calculated % Cr at 2 mm height from the fusion line for all the four shielding gases

Shielding gas	% Cr			
	Base mat	309L	Calculated from the dilution value in Table 3	Practically measured at 2mm from the fusion line using Spectroscopy
100% CO_2	1.42	23.58	16.5	16.10
100% Ar	1.42	23.58	20.70	21.38

It can be seen from the table 6 that as the CO_2 content in the shielding gas increases the % Cr loss increases (see values in column 5). In Ar rich gas blend, namely, 100% Ar, % Cr calculated using the chemical compositions of base and the 309L filler and the dilution for these gases is 20.7. The measured % Cr values at 2mm from the fusion line for these gases is 21.38, which shows increase in % Cr as compared to the calculated values, which is due to the compensation of Cr from the flux (this happens since the electrode which is used is actually made for the use with 100% CO_2 gas and so the flux contains elements accordingly). On the other hand the % Cr calculated for the 100% CO_2 shielding gas is 16.5. The measured % Cr for the 100% CO_2 weld metal at 2mm from the fusion line is 16.1 which is less than the calculated value. This proves that when 100% CO_2 is used as shielding gas there is a loss of Cr due to oxidation.

Results and Discussion 3. - Ferrite number

For the austenitic stainless steel weld overlay ferrite number is one of the main important factors to determine the quality of the weld material. It is well known that carbon is austenite stabilizer and Cr is ferrite stabilizer. So with the increase in the carbon content and decrease in the Cr content there is a decrease in the ferrite number, which is not acceptable. So the above chemical results can be correlated with the measured ferrite number. The Ferrite number was measured at the top surface for all the weld overlays, i.e., for the both the shielding gases, with the help of Feritescope. The Ferrite number, for the weld overlay done using both the shielding gases is as listed in the table 7

Table 7: Effect of carbon and Cr on the ferrite number

Shielding gas	% C at the top surface	% Cr at the top surface	Ferrite number
100%CO_2	0.049	17.8	2 to 5.1
100% Ar	0.031	19.93	7 to 12

It can be seen from the above table that the ferrite number decreases as the CO_2 content in the shielding gas increases. As referred earlier, the increase in % C and the decrease in % Cr, results in reduced value of ferrite number. It can be seen from the above table that there is a systematic reduction in the % Cr as the % CO_2 of the shielding gas increases. For 100% CO_2 it can be observed that the ferrite number is less than (table 7, first value of last column) the ferrite number for 100% Ar. , that is, 7 to 12.

6. Conclusions

1. There is carbon pick up from the shielding gas when 100% CO_2 is used for the low carbon containing austenitic stainless steel overlay.
2. When 100% CO_2 is used as shielding gas, chances of loss of weld metal carbon content due to oxidation and gain of weld metal carbon due to the dissociation of CO_2 to C and O_2, is possible depending upon the molten weld pool carbon content during the weld overlay.
3. The Ferrite number decreases as the CO_2 % in shielding gas increases.

Comparing both the shielding gases, 100% CO_2 gives the best bead profile only the depth of penetration is to be controlled. But there is a high alloying element loss resulting in the decrease of ferrite number. 100% Ar gives poor bead profile characteristics and also the ferrite number is too high than the required limit.

Thus 100% CO_2 shielding gas can be successfully used for SS347T0-1 weld overlay on 1 ¼ Cr – ½ Mo low alloy steel using Flux cored arc welding process for achieving good overlay characteristics provided if we can control the dilution. Research can be done by using CO_2 - Ar gas blends which may give better result than 100% CO_2 shielding gas.

7. Acknowledgement

The current work constitutes the project work of Jayati Girish in the L&T-sponsored M.E. (Welding Technology) programme at the Dept. of Met. & Matls. Engg., M .S. University, Vadodara. The contribution of Larsen & Toubro Ltd. and the Department faculty is gratefully acknowledged. The guidance provided by Dr. D. J. Kotecki is also gratefully acknowledged.

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