

EFFECT OF SHIELDING GASES/ MIXTURES ON PROPERTIES OF SS WELD OVERLAYS ON *Cr-Mo* 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 CO₂ is used as a shielding gas.

Nowadays, stringent requirements are being enforced by many customers/process licensors on restricting the use of 100% CO₂ 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. Four different shielding gas/ mixtures were employed: pure Ar, 90% Ar + 10% CO₂, 80% Ar + 20% CO₂, pure CO₂.

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.

Key words: Shielding gas properties, Stainless steel weld overlay requirements, carbon content, dilution, and the Role of SiO₂ content of flux

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 CO₂ or argon based mixtures containing CO₂, O₂ 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, allowing addition from the flux core, slag shielding and support and improved arc stabilisation 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 CO₂ and Ar – CO₂ gas blends are usually employed to provide shielding, with flux cored wires. The effects of the thermal conductivity, surface tension and oxidation properties of these gases on the stainless steel overlay by FCAW-G process are as follows:

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 CO₂ and produces an arc transfer which is difficult to control. CO₂ has higher thermal conductivity and low surface tension has deeper and wider penetration than 100% Ar. It is also reported that there is higher base metal dilution with the filler metal, in the CO₂ 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.

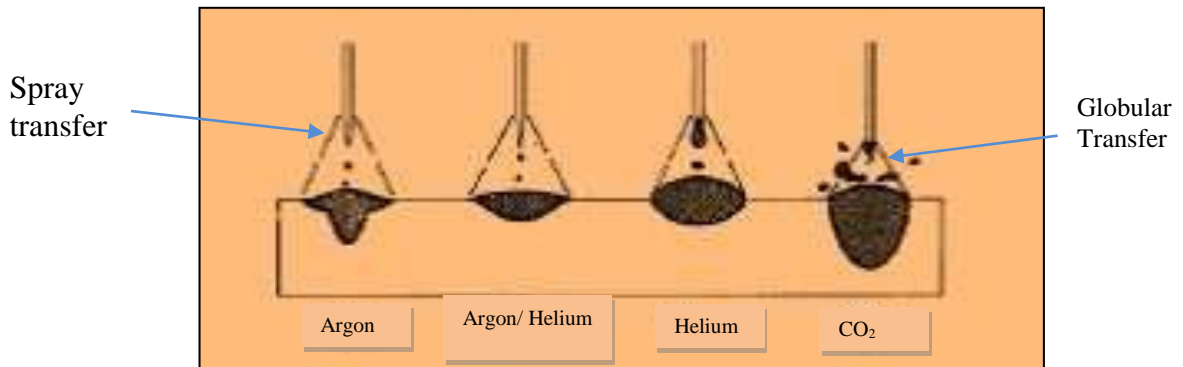


Fig. 1. Effect of thermal conductivity on metal transfer and bead profile

Effect of oxidation potential in the shielding gas:

Oxidation potential of the shielding gas is equal to the % O₂ + ½ % CO₂ [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 CO₂ 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 CO₂ 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.



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 CO₂ and produces iron oxide and carbon monoxide in a reversible reaction:



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



The effect of CO₂ 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 CO₂ 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 CO₂ 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.

Use of Ar/ CO₂ gas blends for Stainless steel welding with GMAW to avoid carbon pick up and alloying elements loss has been reported. With FCAW use of gas mixtures is also successfully done but no much study has been carried out to study the effect on carbon pick up when used with pure CO₂. [5]

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 – CO₂ 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 CO₂ 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 TiO₂, Ca oxide, and SiO₂ reported during chemical analysis of flux). The flux contains mainly stable oxides, smooth arc promoters like TiO₂ 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 SiO₂ 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 SiO₂.

The present study mainly deals with the effect of use of CO₂ 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.

Experimental Details:

100% Ar and argon – CO₂ gas mixture containing 10%, 20% and 100% CO₂ 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.

Table. - 1. Chemical composition of Base material, Barrier layer filler material and final layer filler 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

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 all the four shielding gas/ mixtures.(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 all the four shielding gas/ mixtures. 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 other three shielding gas/ mixtures. 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 used for Ar- CO₂ gas mixtures 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

Figure 2.1, 2.2, 2.3, 2.4 shows the cross sectional view at 10X magnification (macro structure) of the weld overlay, for 100% CO₂, 80% Ar + 20% CO₂, 90% Ar + 10% CO₂, 100% Ar respectively.

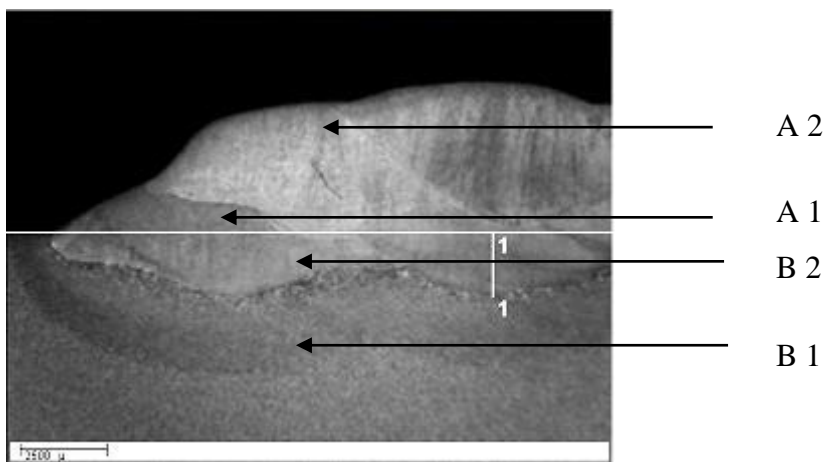


Fig. 2.1 : Depth of penetration and weld bead profile of overlay trial with 100% CO₂ shielding gas (vertical white line 1-1 indicates the depth of penetration of SS 309L in the base material, horizontal white line indicates the base metal top surface)

Here, A 2 = 2.5 mm , A 1 = 1.5 mm , B 2 = depth of penetration is 1694.6 μm

Note:

- A 2 indicates – bead profile of final layer (overlay layer with SS 347)
- A 1 indicates – bead profile of barrier layer above the base line (overlay layer with SS 309L)
- B 2 indicates - barrier layer bead penetration in the base metal
- B 1 indicates – base metal

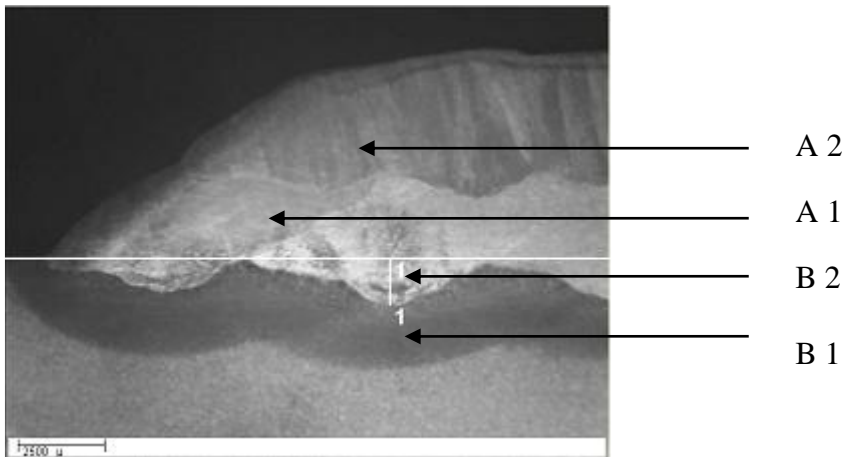


Fig. 2.2 : Depth of penetration and weld bead profile of overlay trial with 80% Ar + 20% CO₂ shielding gas blend (vertical white line 1-1 indicates the depth of penetration of SS 309L in the base material, horizontal white line indicates the base metal top surface)

Here, A 2 = 3 mm , A 1 = 2.5 mm , B 2 = depth of penetration is 1232.4 μm

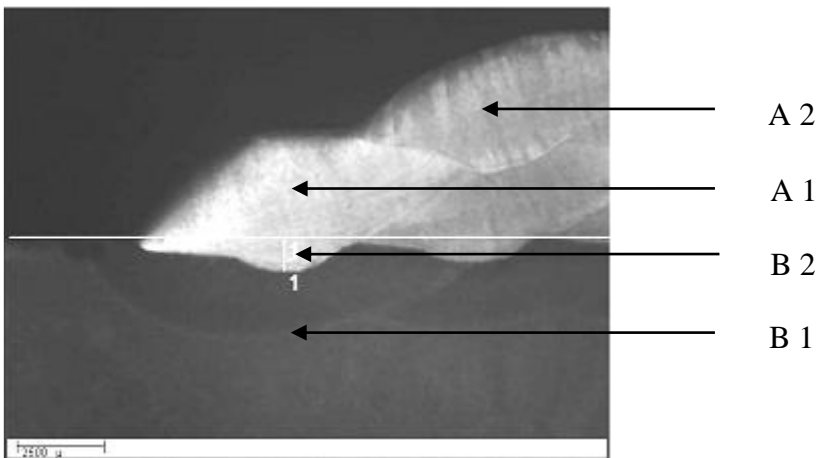


Fig. 2.2 : Depth of penetration and weld bead profile of overlay trial with 90% Ar + 10% CO₂ shielding gas blend (vertical white line 1-1 indicates the depth of penetration of SS 309L in the base material, horizontal white line indicates the base metal top surface)

Here, A 2 = 3.5 mm , A 1 = 3 mm , B 2 = depth of penetration is 873 μm

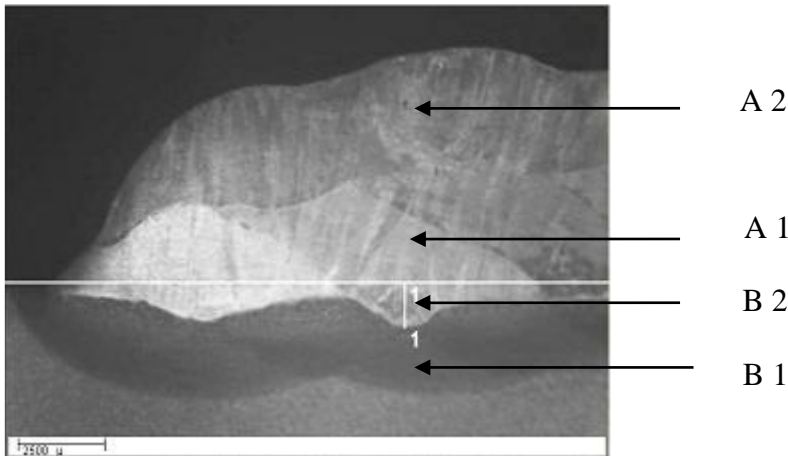


Fig. 2.2 : Depth of penetration and weld bead profile of overlay trial with 100% Ar shielding gas (vertical white line 1-1 indicates the depth of penetration of SS 309L in the base material, horizontal white line indicates the base metal top surface)

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
80% Ar -20% CO ₂	0.09	12.3	9.7	21.2
90% Ar -10% CO ₂	0.09	12.3	10.0	18.4
100% Ar	0.09	12.3	10.7	12.8

It may be seen from the Table 3 that, with the increase in CO₂ percentage in the shielding gas, the dilution increases systematically. This enhanced dilution % is a result of the deeper penetration accounted with CO₂ 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 CO₂ 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 CO₂ 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 each of the four 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.

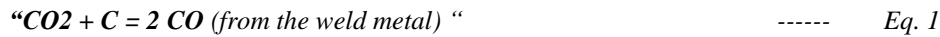
Shielding gas	% Carbon			
	Base material	309L	Calculated from the dilution value in Table 3	Practically measured values by using Leco test
100% CO ₂	0.145	0.025	0.063	0.057
80% Ar -20% CO ₂	0.145	0.025	0.050	0.056
90% Ar -10% CO ₂	0.145	0.025	0.046	0.058
100% Ar	0.145	0.025	0.041	0.028

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 CaF₂ besides metallic powders such as ferroalloys. Although these oxides are generally considered stable, a few of them like SiO₂ are considered to be relatively less stable than the others. This means that oxides like SiO₂ can dissociate in the heat of the arc,

releasing O₂ 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 CO₂, 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



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.



Molten iron reacts with CO₂ and produces iron oxide and carbon monoxide in a reversible reaction:



At arc temperature, some of the carbon monoxide dissociates to carbon and oxygen, as shown in 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 cause a decrease in weld pool carbon content. If on the other hand, the basis carbon content level is lower than 0.05% the CO₂ 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 CO₂ containing mixtures.

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% CO₂, 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%.

Whereas, the carbon level in the deposit, calculated from the base metal and filler metal composition and the dilution with the Ar- CO₂ gas mixtures, is 0.050 and 0.046 respectively for 80-20 and 90 – 10 blends (column 4, row 2 and 3). Here the actual carbon % of 0.056 and 0.058 respectively 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.

The above effects of all the four 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 all the four 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
80% Ar -20% CO ₂	0.056	0.035	0.040	0.0610
90% Ar -10% CO ₂	0.058	0.035	0.039	0.0550
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 CO₂ 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 CO₂ containing gas blends are 0.042, 0.040 and 0.039 (all three values < 0.05%) respectively for 100% CO₂ , 80% Ar + 20% CO₂ and 90% Ar + 10% CO₂ as seen from table 5. Here the actual carbon % of 0.046, 0.061 and 0.055 respectively 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 material	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
80% Ar -20% CO ₂	1.42	23.58	18.9	21.10
90% Ar -10% CO ₂	1.42	23.58	19.60	19.80
100% Ar	1.42	23.58	20.70	21.38

It can be seen from the table 6 that as the CO₂ content in the shielding gas increases the % Cr loss increases (see values in column 5). In Ar rich gas blends, namely, 100% Ar, 90% Ar + 10% CO₂ and 80% Ar + 20% CO₂, % Cr calculated using the chemical compositions of base and the 309L filler and the dilution for these gases is 20.7, 19.6 and 18.9 respectively. The measured % Cr values at 2mm from the fusion line for these gases is 21.38, 19.8 and 21.1 respectively 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% CO₂ gas and so the flux contains elements accordingly). On the other hand the % Cr calculated for the 100% CO₂ shielding gas is 16.5. The measured % Cr for the 100% CO₂ weld metal at 2mm from the fusion line is 16.1 which is less than the calculated value. This proves that when 100% CO₂ 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 four shielding gases, with the help of Ferritescope. The Ferrite number, for the weld overlay done using all the four 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
80% Ar -20% CO ₂	0.057	18.8	4.9 to 7.8
90% Ar -10% CO ₂	0.055	19.01	4.9 to 8.2
100% Ar	0.031	19.93	7 to 12

It can be seen from the above table that the ferrite number decreases as the CO₂ 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 % CO₂ of the shielding gas increases. For 100% CO₂ it can be observed that the ferrite number is least (table 7, first value of last column). The ferrite number for 100% Ar is the highest, that is, 7 to 12.

Conclusions:

1. There is carbon pick up from the shielding gas when CO₂ containing gas blends are used for the low carbon containing austenitic stainless steel overlay.
2. When 100% CO₂ 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 CO₂ to C and O₂, is possible depending upon the molten weld pool carbon content during the weld overlay. Whereas when argon – carbon dioxide gas mixtures are used, it is seen that there is always a pickup of carbon. One of the reason behind this is, that the basis % C is less (less than 0.05%) due to the lesser dilution (as compared to 100% CO₂), in the base metal when gas mixtures are used.
3. The Ferrite number decreases as the CO₂ % in shielding gas increases.

Comparing all the four shielding gases, 100% CO₂ 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. Among the gas mixtures, 80% Ar + 20% CO₂ has a bead profile comparable to 100% CO₂

and there is no much alloying element loss, resulting in achieving the ferrite content as per requirement. Whereas, even 90% Ar – 10% CO₂ gas blend may cause a problem in the bead shape characteristics.

Thus 80% Ar + 20% CO₂ shielding gas blend 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 in place of 100% CO₂ shielding gas.

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