An Approach to Best Welding Practice : Part – XVI

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GMAW process enjoys widespread use because it is operator friendly and for its ability to provide high quality welds, for a wide range of ferrous and non-ferrous alloys, at a low cost. In manufacturing and fabrication where Welding, especially Gas Metal Arc Welding is used extensively divergent views from all possible sources confuse the Welding Engineers and Operators at the planning stage and at the shop floor. This series of articles are particularly focused on the Best Approach to GMAW for optimum effectiveness and efficiency by application of the USEFUL GUIDES and DATA to ensure Quality Welds with maximum productivity for shop floor operations.

In general, GMAW process has the following advantages in practice:

- It has the ability to join a wide range of material types and thicknesses.
- Power source and accessories are simple, operator friendly and equipment components are readily available.
- GMAW has higher electrode efficiencies when compared to other welding processes, usually between 93% and 98%.
- Higher welder efficiencies and operator factor, when compared to other open arc welding processes.
- GMAW process is easily adapted for high-speed robotic, hard automation and semiautomatic welding applications.
- Generally, GMAW has lower cost per length of weld metal deposited when compared to other open arc welding processes.
- Less distortion with GMAW-P (Pulsed Spray Transfer Mode), GMAW-S (Short-Circuit Transfer Mode) and STT (Surface Tension Transfer).
- Handles poor fit-up with GMAW-S and STT modes.
- GMAW can be used effectively for all-position welding.
- GMAW produces excellent weld bead appearance.
- GMAW produces lower hydrogen weld deposit - generally less than 5 mL /100 g of weld metal.
- Lower heat input required when compared to other welding processes.
- In GMAW a minimum of weld spatter and slag makes weld clean up fast and easy.
- Less welding fumes are produced when compared to SMAW (Shielded Metal Arc)

In this article an analytical approach is made on the use of different shielding gases in Gas Metal Arc Welding for effective and efficient welding of different metals and alloys.

Shielding gases are necessary for gas metal arc welding to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. This problem is common to all arc welding processes; for example, in the older Shielded-Metal Arc Welding process (SMAW), the electrode is coated with a solid flux which evolves a protective cloud of carbon dioxide when melted by the arc. In GMAW, however, the electrode wire does not have a flux coating, and a separate shielding gas is employed to protect the weld. This eliminates slag, the hard residue from the flux that builds up after welding and must be chipped off to reveal the completed weld. Typical gas-flow amounts are approximately 20–25 l/min (40–50 ft^3/h).

SELECTION OF SHIELDING GAS FOR GMAW.

In GMAW the selection of the correct shielding gas for a given application is critical to the quality of the finished weld. The major criteria used to make the selection are :

✦ Desired mechanical properties of the deposited weld metal.

✦ Material thickness and joint design.

- The mode of GMAW metal transfer.
- Electrode composition – alloying elements.
- Material condition – the presence of mill scale, corrosion, resistant coatings, or oil.
- The welding position.
- Fit-up conditions.
- Desired penetration profile.
- Desired final weld bead appearance.
- Cost.

Shielding gases respond in different ways under the heat of the arc. The flow of current in the arc and its magnitude has a profound effect on the behavior of the transferred molten droplet. In some welding situations a particular shielding gas will be best to use in one transfer mode, but will not be able to meet the needs of another. Three basic criteria are useful to understand the behavior and the properties of shielding gas:

- The chemical reactivity of the shielding gas with the molten weld puddle
- Ionization potential of the gases used.
- Thermal conductivity of the shielding gases used.

Metal Inert Gas (MIG)	Metal Active Gas (MAG)
Shielding gas is inert like argon	Shielding gas is mixture of active gas (like oxygen) and inert gas
Shielding gas does not disintegrate during welding	Shielding gas disintegrates due to extreme arc heat
Cannot alter weld bead properties	Disintegrated elements can diffuse into weld bead and improve properties
MIG and MAG both are basically GMAW but employ different shielding games	

GMAW Shielding Gases

Shielding gas or Mixtures	Chemical behavior	Metals and applications
Argon	Inert	Virtually all metals except steels
Helium	Inert	Aluminum, magnesium and copper alloys for greater heat input and to minimise porosity.
Ar + He (20-80% to 50-50%)	Inert	Aluminum, magnesium and copper alloys for greater heat input and to minimize porosity (better arc action than 100% helium)
Nitrogen		Greater heat input on copper (Europe)
Ar + 25-30% N_2		Greater heat input on copper (Europe) better arc action than 100% nitrogen
Ar + 1-2% O_2	Slightly oxidizing	Stainless and alloy steels, some deoxidized copper alloys.
Ar + 3-5% O_2	Oxidizing	Carbon and some low-alloy steels
CO_2	Oxidizing	Carbon and some low-alloy steels
Ar + 20-50% CO_2	Oxidizing	Various steels, chlefly short circuiting arc
Ar + 10% CO_2 5% O_2	Oxidizing	Various steels (Europe)
CO_2 + 20% O_2	Oxidizing	Various Steels (Japan)
90% He + 7.5% Ar + 2.5% CO_2	Slightly oxidizing	Stainless steels for good corrosion resistance, short circuiting arc
60-70% He + 25-35% Ar + 4-5% CO_2	Oxidizing	Low-alloy steels for toughness, short circuiting arc.

Base Metal	Shielding Gas	Advantages
Carbon Steels	75% Ar-25% CO_2	Less than 1/8 in. (3.2 mm) thick; high welding speeds without melt through; minimum distortion and spatter.
	Ar + 25-50% CO_2	More than 1/8 in. (3.2 mm) thick; minimum spatter, clean weld appearances, good puddle control in out of position welding.
	CO_2	Deeper penetration and faster welding speeds.
Low-alloy steel	60-70% He + 25-35% Ar + 4-5% CO_2	Minimum reactivity, excellent toughness, art stability, wetting characteristics and bead contour; little spatter.
	75% Ar + 25% CO_2	Fair toughness; excellent arc stability, welding characteristics and bead contour; little spatter.
Stainless Steel	90% He + 7.5% Ar + 2.5 CO_2	No effect on corrosion resistance, small HAZ; no undercutting; minimum distortion.
Aluminium, Copper Magnesium, Nickel and their alloys.	Ar & Ar-He mixtures	Argon satisfactory on thin sections; argon helium mixtures preferred on thicker materials

Details of the arc physics associated with specific shielding gases guide the selection of the best shielding gas for the application are provided below :

Inert Shielding Gases

Argon and helium are the two inert shielding gases used for protecting the molten weld pool of which Argon is the most commonly used inert gas. Compared to helium its thermal conductivity is low. Its energy required to give up an electron, ionization energy, is low, and this results in the finger-like penetration profile associated with its use.

PROPERTIES OF SHILEDING GAS		
FUNCTION	ARGON	HELIUM
Ionization Potential	15.8 eV	24.6 eV
Arc Initiation	Good	Poor
Arc Stability	Good	Poor
Thermal Conductivity (cal/sq.cm./cm/PC/s	0.406×10^{-4}	3.32×10^{-4}
Density (Relative to Air)	1.38	0.137
Cleaning Atction	Good	Poor

However, in order to become a conductive gas, that is, a plasma, the gas must be ionized. Different gases require different amounts of energy to ionize, and this is measured in terms of the ionization energy – eV.

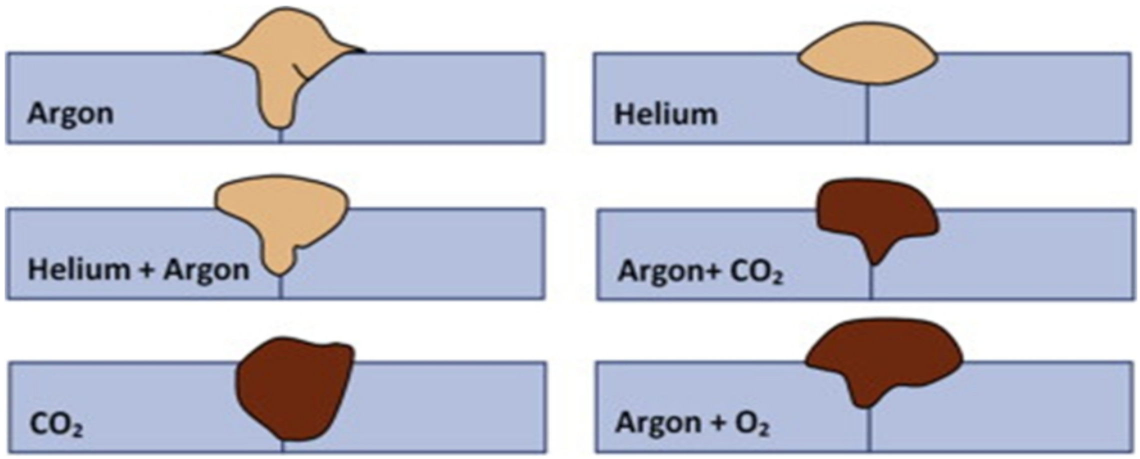
- For argon, the ionization energy is 15.8 eV.
- Helium, on the other hand, has an ionization energy of 24.6 eV. Thus, it is easier to ionize argon than helium. For this reason argon facilitates better arc starting than helium.

Again, the thermal conductivity, or the ability of the gas to transfer thermal energy, is the most important consideration for selecting a shielding gas. High thermal conductivity levels result in more conduction of the thermal energy into the workpiece. The thermal conductivity also affects the shape of the arc and the temperature distribution within the region resulting different Penetration pattern. Argon has a lower thermal conductivity rate - about 10% of the level for both helium and hydrogen. The high thermal conductivity of helium will provide a broader penetration pattern and will reduce the depth of penetration. Gas mixtures with high percentages of argon will result in a penetration profile with a finger-like projection into the base material, and this is due to the lower thermal conductivity of argon.

Argon supports axial spray transfer. Nickel, copper, aluminum, titanium, and magnesium alloyed base materials use 100% argon shielding. Argon, because of its lower ionization energy also assists arc starting. It is the main component gas used in binary (two-part) or ternary (three-part) mixes for GMAW welding. It also increases the molten droplet transfer rate.

Helium is commonly added to the gas mix for stainless and aluminum applications. Its thermal conductivity is very high, resulting in the broad but less deep penetration profile. When in use, arc stability will require additions of arc voltage. Helium additions to argon are effective in reducing the dilution of base material in corrosion resistant applications.

Helium/argon blends are commonly used for welding aluminum greater than 1" (25 mm) thick.



Reactive Shielding Gases

Oxygen, hydrogen, nitrogen, and carbon dioxide (CO_2) are reactive gases. Reactive gases combine chemically with the weld pool to produce a desirable effect.

Carbon Dioxide (CO_2) is inert at room temperature. In the presence of the arc plasma and the molten weld puddle it becomes reactive. In the high energy of the arc plasma the CO_2 molecule breaks apart through a process known as dissociation. In this process, free carbon, carbon monoxide, and oxygen are released from the CO_2 molecule. This occurs at the DC+ anode region of the arc. At the DC - cathode region, which is invariably the work piece for GMAW, the released elements of the CO_2 molecule undergo the process of recombination. During the recombination process higher energy levels prevail and cause the deep and broad penetration profile that characterizes the use of carbon dioxide.

Dissociation and Recombination

During the process of dissociation, the free elements of the CO_2 molecule (carbon, carbon monoxide, and oxygen) mix with the molten weld pool and recombine at the colder cathode region of the arc to form, once again, carbon dioxide. The free oxygen thus released combines chemically with the silicon, manganese, and iron to form oxides of silicon, manganese and iron. Such formed oxides, commonly referred to as silica islands, float to the surface of the weld pool and then solidify into islands on the surface of the finished weld or collect at the toes of a weld. Higher levels of carbon dioxide (higher oxidation potential) increases the amount of slag formed on the surface of the weld. Lower levels of carbon dioxide (lower oxidation potential) increase the amount of alloy, silicon and manganese retained in the weld. As a result, lower carbon dioxide levels, in a binary or ternary shielding gas blend, increase the yield and ultimate tensile strength of a finished weld.

Oxygen (O_2) is an oxidizer that reacts with components in the molten puddle to form oxides. In small additions (1-5%), with a balance of argon, it provides good arc stability and excellent weld bead appearance. The use of deoxidizers within the chemistry of filler alloys compensates for the oxidizing effect of oxygen. Silicon and manganese combine with oxygen to form oxides. Hydrogen (H_2) in small percentages (1-5%), is added to argon for shielding stainless steel and nickel alloys. Its higher thermal conductivity produces a fluid puddle, which promotes improved toe wetting and permits the use of faster travel speeds.

Binary Shielding Gas Blends

Two-part shielding gas blends are the most common and they are typically made up of either argon + helium, argon + CO_2, or argon + oxygen.

Argon + Helium

Argon/helium binary blends are useful for welding nickel based alloys and aluminum. The mode of metal transfer used is either axial spray transfer or pulsed spray transfer. The addition of helium provides more puddle fluidity and flatter bead shape. Helium promotes higher travel speeds. For aluminum GMAW, helium reduces the finger-like projection found with pure argon. Helium is also linked to reducing the appearance of hydrogen pores in welds that are made using aluminum magnesium fillers with 5XXX series base alloys. The argon

SHIELDING GAS SELECTION GUIDE		
CO_2	ARGON + CO_2	ARGON + O_2
Higher Fume Levels	Lower Fume Levels	Lowest Fume Levels
Deeper Penetration	Shallower Penetration	More Rounded Penetration
More Violent or Inconsistant arc transfer	Smoother Arc Transfer	Smoother Atc Transfer
Lower Cost	Higher Cost	Highest Cost
Higher Spatter	Lower Spatter	Lowest Spatter
Less Radiated Heat	More Radiated Heat	Most Radiated Heat
Less Attractive Beads	More Attractive Beads	More Attractive Beads
Pulse Welding NOT Possible	Pulse Welding Possible	Pulse welding Possible
Spray Transfer NOT Possible	Spray Transfer Possible	Spray Transfer Possible

GAS	EFFECTS PRODUCED	ARC BEHAVIOUR	COST
Hydrogen (H_2)	Better bead surface, higher arc temperature, good ignition, higher weld speed	Stable, concentrated arc	Cheap
Argon (Ar)	Inert noble gas, improves oxide breakdown, improved control of the weld pool, confined penetration	Stable arc	Moderate
Helium (He)	Inert noble gas, supplies more heat input, improves penetration and fluidity of weld pool	Unstable, wandering arc	Expensive
Nitrogen (N_2)	Can build nitrides in high temperatures	Wandering arc	Cheap
Carbon Dioxide (CO_2)	Used in small ratio to oxidize and stabilize the arc, improves wettability of the weld bead, deep weld penetration	Unstable arc	Cheap
Oxygen (O_2)	Used in small ratio to oxidize and stabilize the arc, improves weld pool fluidity & weld penetration	Never used alone	Cheap

component provides excellent arc starting and promotes cleaning action on aluminum.

Argon + CO_2

The most commonly found binary gas blends are those used for carbon steel GMAW welding. All four traditional modes of GMAW metal transfer are used with argon/CO_2 binary blends.

They have also enjoyed success in pulsed GMAW applications on stainless steel where the CO_2 does not exceed 4%. Axial spray transfer requires CO_2 contents less than 18%.

Argon + Oxygen

Argon/oxygen blends attain axial spray transfer at lower currents than argon/CO_2 blends. The droplet sizes are smaller, and the weld pool is more fluid. The use of argon + oxygen has historically been associated with high travel speed welding on thin materials. Both stainless steel and carbon steel benefit from the use of argon/oxygen blends.

Ternary Gas Shielding Blends

Three-part shielding gas blends continue to be popular for carbon steel, stainless steel and in restricted cases, nickel alloys. For short-circuiting transfer on carbon steel the addition of 40% helium, to argon and CO_2, as a third component to the shielding gas blend, provides a broader penetration profile. Helium provides greater thermal conductivity for short-circuiting transfer applications on carbon steel and stainless steel base materials. The broader penetration profile and increased sidewall fusion reduces the tendency for incomplete fusion. For stainless steel applications, three-part mixes are quite common. Helium additions of 55% to 90% are added to argon and 2.5% CO_2 for short-circuiting transfer. They are favored for reducing spatter, improving puddle fluidity, and for providing a flatter weld bead shape.

Common Ternary Gas Shielding Blends.

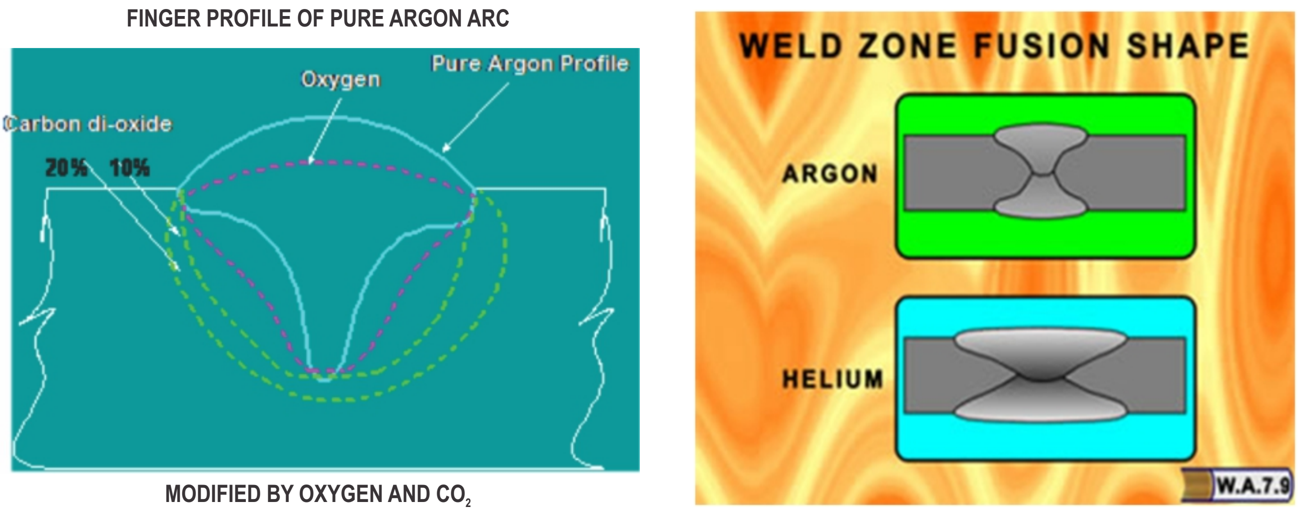


Fig.1 : Bead contour and penetration patterns for various shielding gases

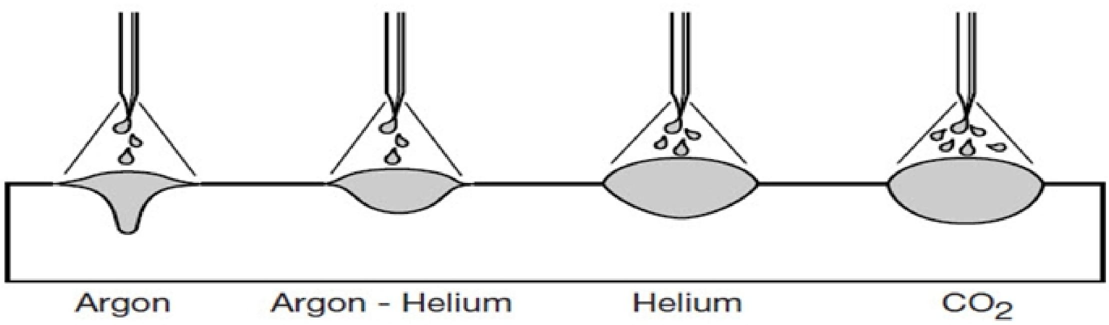
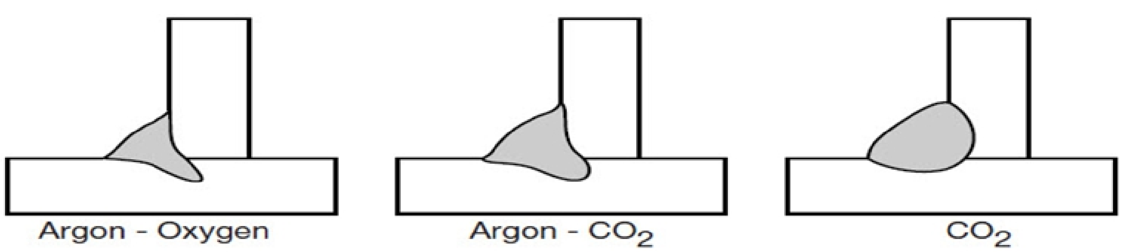
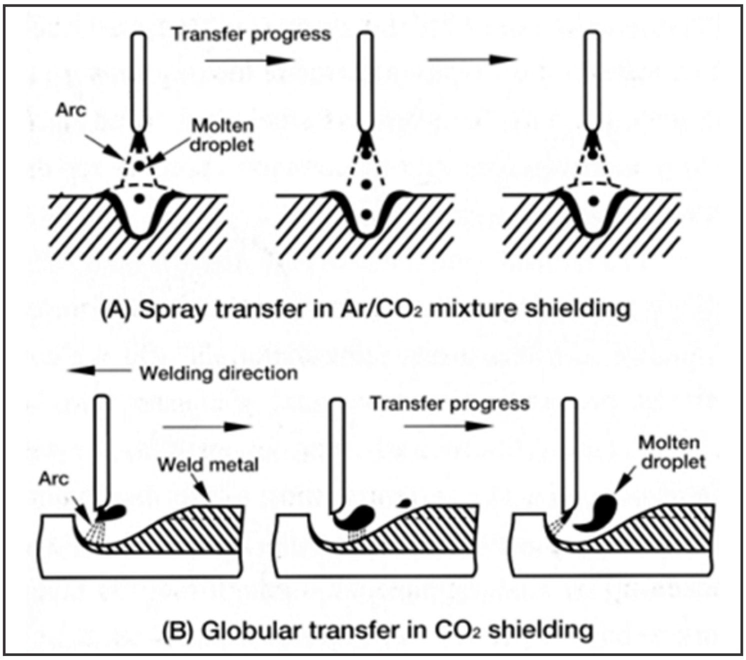


Fig.2 : Relative effect of Oxygen versus CO_2 additions to the argon shield





(A) Spray transfer in Ar/CO2 mixture shielding

(B) Globular transfer in CO2 shielding

	GMAW			FCAW		GTAW		
Gas or Mix	**Carbon**	**Stainless**	**Aluminum**	**Carbon**	**Stainless**	**Carbon**	**Stainless**	**Aluminum**
Ar			X			X	X	X
He								X
CO_2	X			X	X			
Ar/CO_2	X			X	X			
Ar/O_2	X	X						
Ar/He		X	X				X	X
Ar/CO_2/O_2	X							
Ar/H_2							X	
Ar/He/CO_2	X	X		X	X			
He/Ar/CO_2		X						

Process	Wire Dia. (mm)	Voltage	Ampere	Shielding Gas
GMAW Spray Transfer	0.9	28 - 32	165 - 200	98% Argon + 2% Oxygen OR 75% Argon + 25% CO_2
	1.14	30 - 34	180 - 220	
	1.6	30 - 34	230 - 260	
GMAW Short Circuit Transfer	0.9	22 - 25	100 - 140	100% CO_2
	1.14	23 - 26	120 - 150	75% Argon + 25% CO_2

MANUAL TRAVEL, SINGLE PASS, FLAT FILLET WELDS					
MATERIAL THICKNESS (inch)	ELECTRODE SIZE (inch)	WELDING DCRO (arc Volt)	CONDITIONS (Ampere)	GAS FLOW (efh)	TRAVEL SPEED (ipm)
0.025	0.030	15-17	30-50	15-20	15-20
0.031	0.030	15-17	40-60	15-20	18-22
0.037	0.035	15-17	65-85	15-20	35-40
0.050	0.035	17-19	80-100	15-20	35-40
0.062	0.035	17-19	90-110	20-25	30-35
0.078	0.035	18-20	110-130	20-25	25-30
0.125	0.035	19-21	140-160	20-25	20-25
0.125	0.045	20-23	180-200	20-25	27-32
0.187	0.035	19-21	140-160	20-25	14-19
0.187	0.045	20-23	180-200	20-25	18-22
0.250	0.035	19-21	140-160	20-25	10-15
0.250	0.045	20-23	180-200	20-25	12-18

GMAW Axial Spray Transfer data for Solid Composite Steels and Carbon Electrodes and Stainless Steel Solid Wire Electrodes.				
Filler Metal Type	Diameter		Shielding Gas	Current (Amp)
	(Inch)	(mm)		
Carbon and Low Alloy Steel	0.030	(0.8)	90% Argon, 10% CO_2	155 - 165
	0.035	(0.9)	90% Argon, 10% CO_2	215 - 225
	0.052	(1.3)	90% Argon, 10% CO_2	265 - 275
	0.062	(1.6)	90% Argon, 10% CO_2	280 - 290
	0.035	(0.9)	98% Argon, 2% O_2	130 - 140
	0.045	(1.2)	98% Argon, 2% O_2	205 - 215
	0.052	(1.3)	98% Argon, 2% O_2	240 - 250
	0.062	(1.6)	98% Argon, 2% O_2	260 - 275
Carbon and Low Alloy Composite Steel	0.040	(1.0)	90% Argon, 10% CO_2	140 - 150
	0.045	(1.2)	90% Argon, 10% CO_2	160 - 170
	0.052	(1.3)	90% Argon, 10% CO_2	170 - 180
	0 .062	(1.6)	90% Argon, 10% CO_2	220 - 230
Stainless Steel	0.030	(0.8)	98% Argon, 2% O_2	120 - 130
	0. 035	(0.9)	98% Argon, 2% O_2	140 - 150
	0.045	(1.2)	98% Argon, 2% O_2	185 - 195
	0.062	(1.6)	98% Argon, 2% O_2	250 - 200
	0.030	(0.8)	98% Argon, 2% CO_2	130 - 140
	0.035	(0.9)	98% Argon, 2% CO_2	200 - 210
	0.045	(1.2)	98% Argon, 2% CO_2	145 - 155
	0.062	(1.6)	98% Argon, 2% CO_2	255 - 265