Shielding Gases

The atmosphere in the welding zone is displaced by a shielding gas to prevent contamination of the molten weld pool and filler metal. This contamination is mainly caused by nitrogen, oxygen, and water vapor present in the atmosphere.

Nitrogen in solidified steel reduces the ductility and impact strength of the weld metal and can cause cracking. Nitrogen can also cause weld porosity.

Oxygen in steel may combine with carbon in the steel to form carbon monoxide (CO). This gas may be trapped in the solidified weld pool, causing porosity. In addition, oxygen can combine with other elements in steel and form compounds that produce nonmetallic inclusions in the weld metal.

Hydrogen, present in water vapor, is absorbed by molten steel and can produce porosity or underbead cracking on some base metals.

To avoid problems associated with contamination of the weld pool, three basic gases are used for shielding. These gases are argon, helium, and carbon dioxide. Small additions of oxygen and hydrogen have proven beneficial for some applications. Of these gases, only argon and helium are chemically inert.

Carbon Dioxide. Carbon dioxide is a chemically active gas. In the presence of an intense heat such as a welding arc, it dissociates into carbon monoxide and free oxygen and becomes active. The free oxygen reacts with other elements in the weld pool.

Carbon dioxide is often used to weld carbon steel. This gas will not support spray transfer, and it is restricted to short circuiting and globular transfer. Its popularity is due to its availability, low cost, and weld performance. Its major disadvantage is harsh transfer with characteristic spatter.

Argon. Argon is used alone or in combination with other gases for welding ferrous and nonferrous metals. All transfer modes can use argon or its mixes to achieve good weldability, mechanical properties, and arc stability. Argon produces a constricted arc column and high current density, which results in energy concentration over a small surface area.

Helium. Helium is used for applications requiring high heat inputs. It may improve wetting action, depth of fusion, and travel speeds. The weld pool fludity it produces is an advantage when welding aluminum, magnesium, and copper alloys. It is often mixed with argon.

Gas Selection for Gas Metal Arc Welding

Metal Type	Thickness	Transfer Mode	Recommended Shielding Gas	Advantages/Description
Carbon Steel	Up to 14 gauge	Short Circuit	Argon + CO_2 Argon + CO_2 + O_2	Good penetration and distortion control to reduce potential melt-through.
	14 gauge–⅛ in.	Short Circuit	Argon + 8–25% CO_2 Argon + He + CO_2	Higher deposition rates without melt-through. Minimum distortion and spatter. Good pool control for out-of-position welding.
	More than ⅛ in.	Short Circuit	Carbon Dioxide Argon + 15–25% CO_2	High welding speeds. Good penetration and pool control. Applicable for out-of-position welds.
		Short Circuit Globular	Argon + 25% CO_2	Suitable for high-current and high-speed welding.
		Short Circuit	Argon + 50% CO_2	Deep penetration, low spatter, high travel speeds. Good out-of-position welding.
		Short Circular Globular (buried arc)	Carbon Dioxide	Deep penetration and fastest travel speeds but with higher melt-through potential. High-current mechanized welding.
		Spray Transfer	Argon + 1–8% O_2	Good arc stability. Produces a more fluid pool as O_2 increases. Good coalescence and bead contour. Good weld appearance and pool control.
		Spray Transfer	Argon + 5–20% CO_2	Fluid pool and oxidizing to weld metal causing higher amounts of slag and scale as CO_2 increases. Good arc stability, weld soundness, and increasing width of fusion.
		Short Circuit Spray Transfer	Argon + CO_2 + O_2 Argon + He + CO_2 Helium + Ar + CO_2	Applicable to both short circuiting and spray transfer modes. Has wide welding current range and good arc performance. Weld pool has good control, which results in improved weld contour.
		High Current Density Rotational	Ar + He + CO_2 + O_2 Argon + CO_2 + O_2	Used for high deposition rate welding where 15 to 30 lb/h (7 to 14 lb/h) is typical. Special welding equipment and techniques are sometimes required to achieve these deposition levels.
	Over 14 gauge	Pulsed Spray	Argon + 2–8% O_2 Argon + 5–20% CO_2 Argon + CO_2 + O_2 Argon + He + CO_2	Used for both light-gauge and heavy out-of-position weldments. Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges.

(continued)

Metal Type	Thickness	Transfer Mode	Recommended Shielding Gas	Advantages/Description
Low- and High-Alloy Steel	Up to 3⁄32 in.	Short Circuit	Argon + 8–20% CO_2 Helium + Ar + CO_2 Argon + CO_2 + O_2	Good coalescence and bead contour. Good mechanical properties.
		Short Circuit Globular	Argon + 20–50% CO_2	High welding speeds. Good penetration and pool control. Applicable for out-of-position welds. Suitable for high-current and high-speed welding.
	More than 3⁄32 in.	Spray Transfer (High Current Density and Rotational)	Argon + 2% O_2 Argon + 5–10% CO_2 Argon + CO_2 + O_2 Argon + He + CO_2 + O_2	Reduces undercutting. Higher deposition rates and improved bead wetting. Deep penetration and good mechanical properties.
		Pulsed Spray	Argon + 2% O_2 Argon + 5% CO_2 Argon + CO_2 + O_2 Argon + He + CO_2	Used for both light-gauge and heavy out-of-position weldments. Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges.
Steel, Stainless, Nickel, Nickel Alloys	Up to 14 gauge	Short Circuit	Argon + 2–5% CO_2	Good control of melt-through and distortion. Used also for spray arc welding. Pool fluidity sometimes sluggish depending on the base alloy.
	More than 14 gauge	Short Circuit	Helium + 7.5 Ar + 2.5 CO_2 Argon + 2–5% CO_2 Argon + He + CO_2 Helium + Ar + CO_2	Low CO_2 percentages in He mix minimizes carbon pickup, which can cause intergranular corrosion with some alloys. Helium improves wetting action and contour. CO_2 percentages above 5% should be used with caution on some alloys. Applicable for all-position welding.
		Spray Transfer	Argon + 1–2% O_2 Argon + He + CO_2 Helium + Ar + CO_2	Good arc stability. Produces a fluid but controllable weld pool, good coalescence, and bead contour. Minimizes undercutting on heavier thicknesses.
Stainless Steel	More than 14 gauge	Pulsed Spray	Argon + 1–2% O_2 Argon + He + CO_2 Helium + Ar + CO_2 Argon + CO_2 + H_2	Used for both light-gauge and heavy out-of-position weldments. Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges.
Copper, Copper-Nickel Alloys	Up to 1⁄8 in.	Short Circuit	Helium + 10% Ar Helium + 25% Ar Argon + Helium	Good arc stability, weld pool control, and wetting.
	More than 1⁄8 in.	Spray Transfer	Helium + Argon Argon + 50% Helium Argon or Helium	Higher heat input of helium mixtures offset high heat conductivity of heavier gauges. Good wetting and and bead contour. Can be used for out-of-position welding. Using 100% helium on heavier material thickness improves wetting and penetration.
		Pulsed Spray	Argon + Helium	Used for both light-gauge and heavy out-of-position weldments. Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges.
Aluminum	Up to 1⁄2 in.	Spray Transfer Pulsed Spray	Argon	Best metal transfer, arc stability, and plate cleaning. Little or no spatter. Removes oxides when used with DCEP.
	More than 1⁄2 in.	Spray Transfer Pulsed Spray	Helium + 20–50% Argon Argon +Helium	High heat input. Produces fluid pool, flat bead contour, and deep penetration. Minimizes porosity.
Magnesium, Titanium, and other reactive metals	All thicknesses	Spray Transfer	Argon	Excellent cleaning action. Provides more stable arc than helium-rich mixtures.
		Spray Transfer	Argon + 20–70% Helium	Higher heat input and less chance of porosity. More fluid weld pool and improved wetting.

GMAW Transfer Modes

The gas metal arc welding process has distinctive metal transfer modes. The basic transfer modes are short circuiting, globular, and spray. Factors that determine metal transfer are current, wire diameter, arc length, power supply characteristics, and shielding gas.

Short Circuiting Transfer. Short circuiting transfer uses low welding current and arc voltage. The arc characteristics produce a small, fast solidifying weld pool that is generally suited for the joining of thin base metals in all positions and for filling wide root openings. With metal that is greater than ⅛ in. (3.2 mm), extreme care must be taken to prevent incomplete fusion because the heat input is usually low.

In short circuiting transfer, the electrode touches the workpiece and creates a short circuit, which momentarily extinguishes the arc. The power supply senses the electrical resistance and increases current sufficiently to melt off the end of the electrode and reignite the arc.

Globular Transfer. Gobular transfer takes place when current and arc voltage are between the short circuiting and spray transfer range. Globular transfer is characterized by a drop size 2 to 4 times the diameter of the electrode. The mechanism producing globular transfer is generated in a specific current and voltage range.

Spray Transfer. In an argon-rich shielding gas, the electrode metal transfer changes from globular to spray as welding current increases for a given electrode diameter. The change takes place at a value called the globular to spray transition current. Spray transfer has a constricted arc column.

Molten metal transfers across the arc as small droplets, and is axially directed to the workpiece. The transfer rate is high.

Globular-to-Spray Transition Currents for Various Electrodes

Electrode Type	Electrode Diameter in.	mm	Shielding Gas	Spray Arc Transition Current
Low-Carbon Steel	0.023	0.6	98% Argon + 2% O_2	135
	0.030	0.8	98% Argon + 2% O_2	150
	0.035	0.9	98% Argon + 2% O_2	165
	0.045	1.2	98% Argon + 2% O_2	220
	0.062	1.6	98% Argon + 2% O_2	275
	0.035	0.9	95% Argon + 5% O_2	155
	0.045	1.2	95% Argon + 5% O_2	200
	0.062	1.6	95% Argon + 5% O_2	265
	0.035	0.9	92% Argon + 8% CO_2	175
	0.045	1.2	92% Argon + 8% CO_2	225
	0.062	1.6	92% Argon + 8% CO_2	290
	0.035	0.9	85% Argon + 15% CO_2	180
	0.045	1.2	85% Argon + 15% CO_2	240
	0.062	1.6	85% Argon + 15% CO_2	295
	0.035	0.9	80% Argon + 20% CO_2	195
	0.045	1.2	80% Argon + 20% CO_2	255
	0.062	1.6	80% Argon + 20% CO_2	345
Stainless Steel	0.035	0.9	99% Argon + 1% O_2	150
	0.045	1.2	99% Argon + 1% O_2	195
	0.062	1.6	99% Argon + 1% O_2	265
	0.035	0.9	Argon + Helium + CO_2	160
	0.045	1.2	Argon + Helium + CO_2	205
	0.062	1.6	Argon + Helium + CO	280
	0.035	0.9	Argon + H_2 + CO_2	145
	0.045	1.2	Argon + H_2 + CO_2	185
	0.062	1.6	Argon + H_2 + CO_2	255
Aluminum	0.030	0.8	Argon	95
	0.045	1.2	Argon	13
	0.062	1.6	Argon	180
Deoxidized Copper	0.035	0.9	Argon	180
	0.045	1.2	Argon	210
	0.062	1.6	Argon	31
Silicon Bronze	0.035	0.9	Argon	165
	0.045	1.2	Argon	205
	0.062	1.6	Argon	270

Recommended Filler Metals for GMAW

Base Metal	Type	Electrode	AWS Spec
Al and its Alloys	1100	ER1100, ER4043	A5.10
	3003, 3004	ER1100, ER5356	
	5052, 5454	ER5554, ER5356, ER5183	
	5083, 5086, 5456	ER5556, ER5356	
	6061, 6063	ER4043, ER5356	
Stainless Steel	201	ER308	A5.9
	301, 302, 304, 308	ER308	
	304L	ER308L	
	310	ER310	
	316	ER316	
	321	ER321	
	347	ER347	
Carbon Steel	Plain Carbon	ER70S-3, ER70S-1, ER70S-2, ER70S-4, ER70S-5, ER70S-6	A5.18
Nickel and its Alloys	Monel® Alloy 400	ERNiCu-7	A5.14
	Inconel® Alloy 600	ERNiCrFe-5	
Cu and its Alloys	Deoxidized Copper	ECu	A5.7
	Cu-Ni Alloys	ECuNi	
	Mn Bronze	ECuAl-A2	
	Al Bronze	ECuAl-B	
	TW Bronze	ECuSn-A	
Ti and its Alloys	Pure	One or two grades lower	A5.16
	Ti-0.15Pd	ERTi-0.2Pd	
	Ti-5Al-2.5Sn	ERTi-5Al-2.5Sn or pure	
Mg Alloys	AZ10A	ERAZ61A, ERAZ92A	A5.19
	AZ31B, AZ61A, AZ80A	ERAZ61A, ERAZ92A	
	ZE10A	ERAZ61A, ERAZ92A	
	ZK21A	ERAZ61A, ERAZ92A	
	AZ63A, AZ81A, AZ91C	ERAZ92A	
	AZ92A, AM100A	ERAZ92A	
	HK31A, HM21A, HM31A	EREZ33A	
	LA141A	EREZ33A	

Potential Problems and Troubleshooting

Hydrogen

An awareness of the potential problems of hydrogen embrittlement is important even though it is less likely to occur with GMAW since a hygroscopic flux or coating is not used. However, other hydrogen sources must be considered. The shielding gas must be sufficiently low in moisture content. This is normally well controlled by the gas supplier, but may have to be checked. Oil, grease, or drawing compounds on the electrode or the base metal may also become potential sources for hydrogen pick-up in the weld metal.

Electrode manufacturers are aware of the need for cleanliness and take special care to provide a clean electrode. Contaminants are more likely to be introduced during handling in the user facility. The user who is aware of such possibilities may avoid serious problems, particularly in welding hardenable steels. The same awareness is necessary in welding aluminum where the potential problem is porosity caused by the relatively low solubility of hydrogen in solidified aluminum, rather than hydrogen embrittlement.

Oxygen and Nitrogen

Oxygen and nitrogen are potentially greater problems than hydrogen in the GMAW process. If the shielding gas is not completely inert or adequately protective, these elements may be readily absorbed from the atmosphere. The composition of welding electrodes is adjusted to provide adequate deoxidization elements to offset this tendency and avoid porosity to ensure sound deposits.

Even so, GMAW deposits made in high-strength steels do not have as much ductility as those made with the gas tungsten arc welding (GTAW) process. Studies have also indicated that a gas shielding mixture of 98% argon and 2% oxygen or 80% argon and 20% CO_2 results in GMAW weld properties similar to those of the SMAW process. If the active component of the gas is increased (as in 50% argon and 50% CO_2 mixture or 100% CO_2), the impact strength of the resultant weld will be lower.

Cleanliness

Cleanliness in the use of bare electrodes in GMAW is more critical than with SMAW or submerged arc welding (SAW). The fluxing compounds present in the SMAW and SAW shielding slag scavenge and clean the molten weld deposit of oxides and gas-forming compounds. These fluxing slags are not normally present in GMAW, and thus, there may be a greater chance for porosity to form.

Some of the more common discontinuities with the GMAW process are listed below. The possible cause number corresponds to the corrective action number.

Undercutting

Possible Causes

1) Travel speed too high

2) Welding voltage too high

3) Excessive welding current

4) Insufficient dwell

5) Gun angle

Corrective Actions

1) Use slower travel speed

2) Lower the voltage

3) Reduce wire feed speed

4) Increase dwell at edge of molten weld pool

5) Direct arc via gun angle so arc force can aid in metal placement

Porosity

Possible Causes

1) Inadequate shielding gas coverage

2) Gas contamination

3) Electrode contamination

4) Workpiece contamination

5) Arc voltage too high

6) Excess contact tube-to-work distance

Corrective Actions

1) Increase gas flow to displace all air from the weld zone. Decrease excessive gas flow to avoid turbulence and entrapment of air in the weld zone. Remove spatter buildup in the nozzle. Eliminate any leaks in the gas line. Eliminate drafts (e.g. fans, open doors) blowing into the welding arc. Eliminate frozen (clogged) regulator in CO_2 welding by manifolding several cylinders or through the use of heaters. Use slower travel speed. Reduce nozzle-to-work distance. Hold gun at end of weld until molten metal solidifies.

2) Use welding grade shielding gas.

3) Use only clean and dry electrode.

4) Remove all grease, oil, moisture, rust, paint, and dirt from work surface before welding. Use more highly deoxidizing electrode.

5) Reduce voltage.

6) Reduce electrode extension.

Incomplete Fusion

Possible Causes

1) Weld zone surfaces not free of film or excessive oxides.

2) Insufficient heat input.

3) Too large a weld pool.

4) Improper weld technique.

5) Improper joint design.

6) Excessive travel speed.

Corrective Actions

1) Clean all groove faces and weld zone surfaces of any mill scale impurities prior to welding.

2) Increase the wire feed speed and the arc voltage. Reduce electrode extension.

3) Minimize excessive weaving to produce a more controllable weld pool. Increase the travel speed.

4) When using a weaving technique, dwell momentarily on the side walls of the groove. Provide improved access at root of joints. Keep electrode directed at the leading edge of the weld pool. Provide proper transverse angulation.

5) Provide included angle of groove joint large enough to allow access to bottom of the groove and sidewalls with proper electrode extension and arc characteristics, or use a J or U groove.

6) Reduce travel speed.

Incomplete Joint Penetration

Possible Causes

1) Improper joint preparation.

2) Improper weld technique.

3) Inadequate heat input.

Corrective Actions

1) Joint preparation and design must be adequate to provide proper access to the bottom of the groove while maintaining proper electrode extension and arc characteristics.

Reduce excessively large root face. Provide or increase root opening in butt joints and increase depth of back gouge.

2) Maintain electrode angle normal to work surface to achieve maximum penetration. Keep arc in leading edge of the weld pool.

3) Increase the wire feed speed (welding current). Maintain proper electrode extension.

Excessive Melt-Through

Possible Causes
1) Excessive heat input

2) Improper joint penetration

Corrective Actions
1) Reduce both wire feed speed (welding current) and accordingly the voltage. Increase the travel speed.

2) Reduce excessive root opening. Increase root face dimension.

Weld Metal Cracks

Possible Causes
1) Improper joint design.

2) Too high a weld depth-to-width ratio.

3) Too small a weld bead (particularly fillet and root beads).

4) Heat input too high causing excessive shrinkage and distortion.

5) Hot shortness.

6) High restraint of joint members.

7) Rapid cooling in the crater.

Corrective Actions
1) Maintain proper groove dimensions to allow deposition of adequate filler metal or weld cross section in order to overcome restraint conditions.

2) Either increase arc voltage or decrease the current or both to widen the weld bead or decrease the penetration. Adjust the groove angle (joint preparation).

3) Decrease travel speed to increase cross section of deposit.

4) Reduce either current or voltage or both. Increase travel speed.

5) Use ferrous electrode with sufficient manganese (use shorter arc length to minimize loss of manganese across the arc). Adjust the groove angle to allow adequate percentage of filler metal addition. Adjust pass deposition sequence to reduce restraint on the weld during cooling. Change to another filler metal providing desired characteristics.

6) Use preheat to reduce magnitude of the residual stresses. Adjust welding sequence to reduce restraint conditions.

7) Use a tapered power control to reduce the end of a weld. Fill craters adequately.

Heat-Affected Zone (HAZ) Cracks

Possible Causes
1) Hardening in the heat-affected zone.

2) Residual stresses too high.

3) Hydrogen embrittlement.

Corrective Actions
1) Preheat to retard cooling rate.

2) Use stress relief heat treatment.

3) Use clean electrode shielding. Use dry shielding gas. Remove contaminants from the base metal. Hold weld at elevated temperatures for several hours before pooling (temperature and time required to diffuse hydrogen are dependent on base metal type).

General Cracks

Possible Causes
1) Presence of notches or points of high stress concentrations.

Corrective Actions
1) Avoid undercutting. Limit reinforcements. Maintain maximum reentrant angle of reinforcement at toe of weld. Provide adequate root penetration.

Nonmetallic Inclusions

Possible Causes
1) Multipass, short circuiting arc welding.

Corrective Actions
1) Remove glassy slag islands from weld deposits before making subsequent passes.

Film-Type Inclusions

Possible Causes
1) High travel speeds.

Corrective Actions
1) Reduce travel speed. Use more highly deoxidized electrode. Increase arc voltage.

Wavy Weld Bead

Possible Causes
1) Excessive electrode extension.

2) Hard electrode with small cast (small radius of curvature).

Corrective Actions
1) Reduce electrode extension.

2) Use straightening rolls.

Overlap or Sagging

Possible Causes
1) Welding out of flat position in spray transfer mode.

2) Weld too narrow for the amount of reinforcement.

Corrective Actions
1) Weld in the flat position especially when using high currents. Increase travel speed. Adjust gun angle.

2) Increase the arc voltage.

Humping

Possible Cause
1) Excessive travel speed.

Corrective Action
1) Reduce travel speed.

Spatter

Possible Causes
1) Shorting of the electrode and droplet to the work.

2) Excessive spatter when using CO_2 gas shielding.

3) Welding in globular transfer range (argon shield).

Corrective Actions
1) Raise the arc voltage. Limit the rate of current rise by increasing inductive reactance in the welding circuit (short circuiting transfer).

2) Decrease arc voltage, or increase electrode feed speed to "bury" the arc and thus contain the spatter.

3) Increase current to an axial spray transfer range.

Unmelted Electrode on Root Side (Whiskers)

Possible Cause
1) Improper weld technique

Corrective Actions
1) Reduce the travel speed. Use weaving motion. Increase electrode extension. Decrease wire feed speed.◆