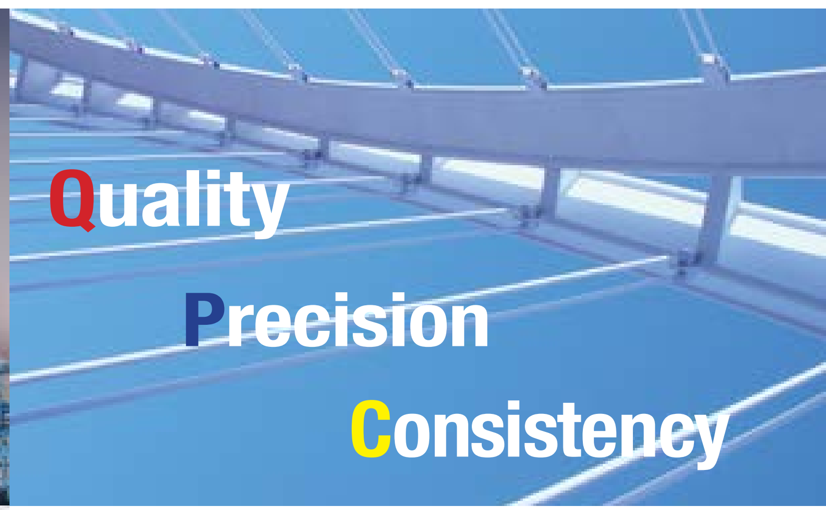
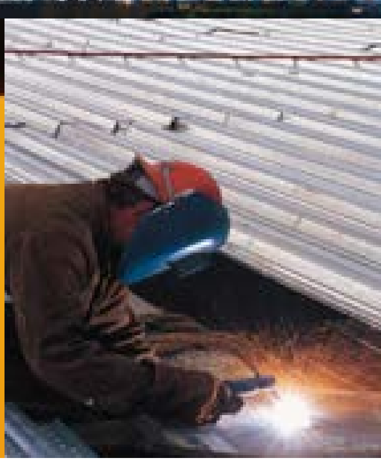
# AMERICAN
## FILLER METALS

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# Reference & Useful Information

## Inch & Millimeter Decimal Equivalents of Fractions of an Inch

| Inch | | Millimeter |
|---|---|---|
| Fraction | Decimal | |
| 1/64 | .015 625 | 0.396 875 |
| 1/32 | .031 250 | 0.793 750 |
| 3/64 | .062 500 | 1.190 625 |
| *1/16* | *.078 125* | *1.587 500* |
| 5/64 | .093 750 | 1.984 375 |
| 3/32 | .109 375 | 2.381 250 |
| 7/64 | .125 000 | 2.778 125 |
| *1/8* | *.140 625* | *3.175 000* |
| 9/64 | .156 250 | 3.571 875 |
| *5/32* | *.171 875* | *3.968 750* |
| 11/64 | .187 500 | 4.365 625 |
| *3/16* | *.203 125* | *4.762 500* |
| 13/64 | .203 125 | 5.159 375 |
| 7/32 | .218 750 | 5.556 250 |
| 15/64 | .234 375 | 5.953 125 |
| 1/4 | .250 000 | 6.350 000 |
| 17/64 | .265 625 | 6.746 875 |
| 9/32 | .281 250 | 7.143 750 |
| 19/64 | .296 875 | 7.540 625 |
| 5/16 | .312 500 | 7.937 500 |
| 21/64 | .328 125 | 8.334 375 |
| 11/32 | .343 750 | 8.731 250 |
| 23/64 | .359 375 | 9.128 125 |
| 3/8 | .375 000 | 9.525 000 |
| 25/64 | .390 625 | 9.921 875 |
| 13/32 | .406 250 | 10.318 750 |
| 27/64 | .421 875 | 10.715 625 |
| 7/16 | .437 500 | 11.112 500 |
| 29/64 | .453 125 | 11.509 375 |
| 15/32 | .468 750 | 11.906 250 |
| 31/64 | .484 375 | 12.303 125 |
| 1/2 | .500 000 | 12.700 000 |

| Inch | | Millimeter |
|---|---|---|
| Fraction | Decimal | |
| 33/64 | .515 625 | 13.096 875 |
| 17/32 | .531 250 | 13.493 750 |
| 35/64 | .546 250 | 13.890 625 |
| 9/16 | .562 500 | 14.287 500 |
| 37/64 | .578 125 | 14.684 375 |
| 19/32 | .593 750 | 15.081 250 |
| 39/64 | .609 375 | 15.478 125 |
| 5/8 | .625 000 | 15.875 000 |
| 41/64 | .640 625 | 16.271 875 |
| 21/32 | .656 250 | 16.668 750 |
| 43/64 | .671 875 | 17.065 625 |
| 11/16 | .687 500 | 17.462 500 |
| 45/64 | .703 125 | 17.859 375 |
| 23/32 | .718 750 | 18.256 250 |
| 47/64 | .734 375 | 18.653 125 |
| 3/4 | .750 000 | 19.050 000 |
| 49/64 | .765 625 | 19.446 875 |
| 25/32 | .781 250 | 19.843 750 |
| 51/64 | .796 875 | 20.240 625 |
| 13/16 | .812 500 | 20.637 500 |
| 53/64 | .828 125 | 21.034 375 |
| 27/32 | .843 750 | 21.431 250 |
| 55/64 | .859 375 | 21.828 125 |
| 7/8 | .875 000 | 22.225 000 |
| 57/64 | .890 625 | 22.621 875 |
| 29/32 | .906 250 | 23.018 750 |
| 59/64 | .921 875 | 23.415 625 |
| 15/16 | .937 500 | 23.812 500 |
| 61/64 | .953 125 | 24.209 375 |
| 31/32 | .968 750 | 24.606 250 |
| 63/64 | .984 375 | 25.003 125 |
| 1 | 1.000 000 | 25.400 000 |

## Inch - Millimeter Conversion Chart (1 Inch = 25.4 Millimeters)

| Gauge | Inch Decimal | Millimeters | Gauge | Inch Decimal | Millimeters |
|---|---|---|---|---|---|
| 30 | .0120 | .3048 | 16 | .0598 | 1.5189 |
| 29 | .0135 | .3429 | 15 | .0673 | 1.7094 |
| 28 | .0149 | .3785 | 14 | .0747 | 1.8974 |
| 27 | .0164 | .4166 | 13 | .0897 | 2.2784 |
| 26 | .0179 | .4547 | 12 | .1046 | 2.6568 |
| 25 | .0209 | .5309 | 11 | .1196 | 3.0378 |
| 24 | .0239 | .6071 | 10 | .1345 | 3.4163 |
| 23 | .0269 | .6833 | 9 | .1495 | 3.7973 |
| 22 | .0299 | .7595 | 8 | .1644 | 4.1758 |
| 21 | .0329 | .8357 | 7 | .1793 | 4.5542 |
| 20 | .0359 | .9119 | 6 | .1943 | 4.9352 |
| 19 | .0418 | 1.0617 | 5 | .2092 | 5.3137 |
| 18 | .0478 | 1.2141 | 4 | .2242 | 5.6947 |
| 17 | .0538 | 1.3665 | 3 | .2391 | 6.0731 |

## Weights & Measures

| | |
|---|---|
| 1 pound (lb) | = 453.6 grams |
| 100 lb | = 45.36 kilograms |
| 112 lb | = 50.80 kilograms |
| 1 short ton (2,000 lb) | = 907.2 kilograms |
| 1 long ton (2,240 lb) | =1,016 kilograms |
| 1 kilo grams | = 2,2046 lbs |
| 100 kilograms | = 220.46 lbs |
| 1 metric ton (1,000 kilograms) | = 2,204.6 lbs |
| | = 0.9842 gross ton |
| | = 1.1023 net tons |
| 1 inch | = 25.40 millimeters |
| 1 foot (12 inches) | = 30.48 centimeters |
| 1 yard (3 feet) | = 91.44 centimeters |
| 1 mile (1,760 yard) | = 1,609.35 meters |
| 1 millimeter | = 0.03937 inches |
| 1 centimeter | = 0.3937 inches |
| 1 meter | = 39.37 inches |
| | = 3.2808 feet |

| | |
|---|---|
| 1 kilometer | = 0.62137 mile |
| | = 3,280 feet |
| 1 square inch | = 6.4516 square centimeters |
| | = 645.16 millimeters |
| 1 square foot | = 0.0929 square meter |
| 1 square yard | = 0.8361 square meter |
| 1 square millimeter | = 0.00155 square inch |
| 1 square centimeter | = 0.155 square inch |
| 1 square meter | = 10.7639 square feet |
| | = 1.196 square yards |
| 1 pound per foot | = 1.4882 kilograms per meter |
| 1 pound per yard | = 0.4961 kilograms per meter |
| 1 pound per square inch | = 0.0703 kilograms per square centimeter |
| 1 pound per square foot | = 4.8825 kilograms per square meter |
| 1 kilogram per meter | = 0.6720 pounds per feet |
| 1 kilogram per square millimeter | = 1,422.32 pounds per square inch |
| 1 kilogram per square centimeter | = 14.2232 pounds per square inch |
| 1 kilogram per square meter | = 0.2048 pounds per square foot |
| | = 1.8433 pounds per square yard |

## Feet Per Pound - Stainless Rounds

| Diameter Inches | Feet Per Pound | Diameter Inches | Feet Per Pound | Diameter Inches | Feet Per Pound |
|---|---|---|---|---|---|
| .016 | 1,445 | .057 | 114 | .098 | 38.4 |
| .017 | 1,280 | .058 | 110 | .099 | 37.7 |
| .018 | 1,141 | .059 | 106 | .100 | 36.9 |
| .019 | 1,024 | .060 | 103 | .105 | 33.7 |
| .020 | 925 | .061 | 99 | .109 | 31.3 |
| .021 | 839 | .062 | 96 | .114 | 28.5 |
| .022 | 764 | .063 | 93 | .120 | 25.8 |
| .023 | 699 | .064 | 90 | .125 | 23.6 |
| .024 | 642 | .065 | 88 | .135 | 20.6 |
| .025 | 592 | .066 | 85 | .140 | 18.8 |
| .026 | 547 | .067 | 82 | .148 | 17.1 |
| .027 | 507 | .068 | 80 | .156 | 15.1 |
| .028 | 472 | .069 | 78 | .162 | 14.3 |
| .029 | 440 | .070 | 75 | .171 | 12.64 |
| .030 | 411 | .071 | 73 | .177 | 11.97 |
| .031 | 385 | .072 | 71 | .178 | 10.57 |
| .032 | 361 | .073 | 69 | .192 | 10.17 |
| .033 | 340 | .074 | 68 | .203 | 8.97 |
| .034 | 320 | .075 | 65.7 | .207 | 8.75 |
| .035 | 302 | .076 | 64 | .218 | 7.78 |
| .036 | 285 | .077 | 62.3 | .225 | 7.39 |
| .037 | 270 | .078 | 60.7 | .234 | 6.75 |
| .038 | 256 | .079 | 59.2 | .243 | 6.31 |
| .039 | 243 | .080 | 57.7 | .250 | 5.92 |
| .040 | 231 | .081 | 56.3 | .262 | 5.44 |
| .041 | 220 | .082 | 54.9 | .283 | 4.68 |
| .042 | 210 | .083 | 53.6 | .306 | 3.99 |
| .043 | 200 | .084 | 52.3 | .3125 | 3.84 |
| .044 | 191 | .085 | 51.1 | .331 | 3.42 |
| .045 | 183 | .086 | 49.9 | .344 | 3.17 |
| .046 | 175 | .087 | 48.8 | .3625 | 2.85 |
| .047 | 167 | .088 | 47.7 | .375 | 2.67 |
| .048 | 160 | .089 | 46.6 | .394 | 2.42 |
| .049 | 154 | .090 | 45.6 | .406 | 2.27 |
| .050 | 148 | .091 | 44.6 | .430 | 2.02 |
| .051 | 142 | .092 | 43.6 | .4375 | 1.96 |
| .052 | 137 | .093 | 42.7 | .462 | 1.76 |
| .053 | 132 | .094 | 41.8 | .469 | 1.71 |
| .054 | 127 | .095 | 40.9 | .490 | 1.56 |
| .055 | 122 | .096 | 40.1 | .500 | 1.50 |
| .056 | 118 | .097 | 39.2 | | |

## General Conversion Formulas

| Covert To | Formula | Example |
|---|---|---|
| ksi (1,000 lb/in²)- MPa (N/mm²) | ksi X 6.8948 | 50.77 ksi =350 MPa |
| MPa (N/mm²) - ksi (1,000 lb/in²) | MPa X 0.14503774 | 350 MPa = 50.77 ksi |
| psi (1 lb/in²)- MPa (N/mm²) | psi X 0.0068948 | 39,160 psi = 270 MPa |
| MPa (N/mm²) - psi (1 lb/in²) | MPa X 145.03774 | 270 MPa = 39,160 psi |

| Covert To | Formula | Example |
|---|---|---|
| ft/lb - J | ft/lb X 1.35582 | 50 ft/lb = 67.79 J |
| J - ft/lb | J X 0.737562 | 67.79 J = 50 ft/lb |
| ft/lb - kg/m | ft/lb X 0.138255 | 50 ft/lb = 6.91275 kg/m |
| kg/m - ft/lb | kg/m X 7.23301 | 6.913 kg/m = 49.999899 ft/lb |
| lb/ft - kg/m | lb/ft X 1.48817 | 5 lb/ft = 7.44085 kg/m |
| kg/m - lb/ft | kg/m X 0.67196624 | 7.44085 kg/m = 5 lb/ft |

| Covert To | Formula | Example |
|---|---|---|
| mm - in | mm X 0.03937008 | 10 mm = 0.394 in |
| in - mm | in X 25.4 | 2 in = 50.80 mm |
| mm - ft | mm X 0.00328084 | 304.8 mm = 1.00 ft |
| ft - mm | ft X 304.8 | 3 ft = 914.4 mm |

| Covert To | Formula | Example |
|---|---|---|
| kg - lb | kilograms X 2.2046 | 10 kg = 22.046 lb |
| lb - kg | pounds X 0.453597024 | 10 lb = 4.536 kg |

# Recommended Gases for Welding

## GTAW Gases:

***Shielding Gases*** *(see Table 1)*

***Argon (SG-A)***

Argon, an inert gas, is the most commonly used shielding gas for the GTAW process.
It has low thermal conductivity and provides a narrow arc column.
Argon affords welders considerable manipulative flexibility.
Its low arc voltage characteristic permits arc length variations with minimal influence on arc energy & weld bead shape.
Argon provides relatively easy arc initiation due to its low ionization potential.
Argon is preferred over helium for alternating current (AC) welding applications because of enhanced cleaning action, arc stability, and weld appearance.
Argon is denser than air, providing adequate shielding at lower flow rates than helium.

***Helium (SG-He)***

Helium is a chemically inert shielding gas that has high thermal conductivity and high ionization potential.
Arc voltages are higher with helium than argon for a given current setting and arc length.
These attributes increase the heat input which affects bead width and depth of arc penetration.
For this reason, helium is often mixed with argon for welding base metals with high melting temperatures or high thermal conductivity.
When using direct current electrode negative (DCEN) for mechanized GTAW of aluminum, helium shielding provides greater depth of fusion and higher travel speeds than argon.
Mechanical removal of surface oxides is generally required when using GTAW with DCEN and helium shielding gas for welding aluminum.
Although it offers definite advantages for some applications, helium produces a less stable arc and less desirable arc starting characteristics than argon.
Helium usually requires higher shielding flow rates than argon.

***Argon+Helium (SG-AHe)***

Helium is added to argon to take advantage of the best operating characteristics of each gas.
The superior arc starting and stable arc characteristics of argon with helium's higher thermal conductivity produce high-quality gas tungsten arc welds on aluminum using alternating current.
Increased travel speeds and greater depth of fusion, for both manual and mechanized welding of nonferrous alloys can be produced as helium content is increased.
Helium content usually ranges between 25% and 75%.

***Argon+Hydrogen (SG-AH)***

Additions of hydrogen increase the heat input, permitting faster travel, increased depth of fusion, better wetting action, and broader weld bead profile.
Argon-hydrogen mixtures provide a reducing atmosphere in the arc, removing oxygen from the weld area.
A typical argon-hydrogen mixture is 95% argon and 5% hydrogen.
Mixtures of argon and hydrogen are frequently used to weld austenitic stainless steels. nickel, and nickel based alloys.
Argon-hydrogen mixtures should not be used to weld carbon or low alloy steels because of the potential of hydrogen-induced cracking,.

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# Recommended Gases for Welding

***Special safety precautions are required when mixing argon and hydrogen.***

***Users should NOT mix argon and hydrogen from separate cylinders without the use of approved mixing equipment.***

***Shielding Gas Flow Rates.***

Shielding gas flow rates are influenced by the factors listed below.
For example, the type of gas affects flow rates that may be required to produce a satisfactory weld.
Argon can be used for GTAW on all base metals.
Typical flow rates are from 10 scfh to 35 scfh [5 L/min to 16 L/min].
Helium is less dense than argon and therefore may require higher flow rates.

(1) Type of base metal
(2) Type and position of joint
(3) Torch position
(4) Amperage
(5) Type of gas
(6) Gas nozzle type and size
(7) Manual or automatic welding mode
(8) Outdoor conditions such as wind

## Recommended Types of Current, Tungsten Electrodes, and Shielding Gases for GTAW of Different Metals and Alloys *[Table 1]*

| Metal | Thickness | Type of Current (1), (2) | Tungsten Electrode Type (3) | Shielding Gases |
|---|---|---|---|---|
| Aluminum Alloys | All | AC | Pure or Zirconiated | Argon or Argon-Helium |
| | >1/8 in. [3 mm] | DCEN | Thoriated | Argon-Helium or Argon |
| | <1/8 in. [3 mm] | DCEP | Thoriated or Zirconiated | Argon |
| Copper & Copper Alloys | All | DCEN | Thoriated | Helium or Argon-Helium |
| | <1/8 in. [3 mm] | AC | Pure or Zirconiated | Argon |
| Nickel & Nickel Alloys | All | DCEN | Thoriated | Argon |
| Magnesium Alloys | All | AC | Pure or Zirconiated | Argon |
| | <1/8 in. [3 mm] | DCEP | Zirconiated or Thoriated | Argon |
| Plain Carbon & Low Alloy Steels | All | DCEN | Thoriated or Zirconiated | Argon or Argon-Helium |
| | <1/8 in. [3 mm] | AC | Thoriated | Argon |
| Stainless Steel | All | DCEN | Thoriated or Zirconiated | Argon, Argon-Helium, Hydrogen (5% Max.) (4) |
| | | AC | Thoriated | Argon |
| Titanium Alloys | All | DCEN | Thoriated | Argon, Argon-Helium |

***Notes;***
(1) Where AC is listed, variable polarity or pulse current could be used.
(2) AC = Alternating current: DCEP = Direct current electrode positive; DCEN = Direct current electrode negative.
(3) Where thoriated tungsten electrodes are recommended, ceriated or lanthanated electrodes may also be used.
(4) Austenitic stainless steels only.

## GMAW Gases:

***Process Description***

Gas metal arc welding (GMAW) is a welding process that uses an arc between a continuous filler metal electrode (which can be solid or metal cored) and the weld pool.
The arc continuously melts the wire as it is fed to the weld pool, and both are protected from the atmosphere by the flow of shielding gas.

***Process Variations and Metal Transfer Modes.***

The GMAW process includes distinctive metal transfer modes: short-circuiting transfer, globular transfer (in argon and in carbon dioxide), spray transfer, pulsed spray transfer, and high-current-density rotational or non-rotational spray (high deposition) transfer.
Factors that determine metal transfer mode are current, electrode alloy type, electrode diameter, arc length, power supply characteristics, and shielding gas.

***Short-Circuiting Transfer Mode.***

The short-circuiting transfer mode occurs at low welding current and arc voltage.
The arc characteristics of this transfer mode produces a small fast-solidifying weld pool that is generally suited for the joining of thin base metals in all positions, and for the filling of wide root openings.
With material that is thicker than 1/8 in. 13 [mm], extreme care must be taken to prevent incomplete fusion.
Since heat input is usually low, distortion of the work piece is minimized.
The electrode feeds at a constant speed and contacts the work piece or molten pool, at which time a short circuit occurs.
The current from the power supply increases and heats the wire to a point where the end of the wire melts off, creating an arc between the wire end and the work piece. At that point in the sequence, there is no metal transfer across the arc.
The welding wire short-circuiting sequence repeats itself from 50 to 250 times per second.

***Globular Transfer Mode.***

Globular transfer takes place when the current and arc voltage are between the short-circuiting and spray transfer range.
Regardless of the type of shielding gas, carbon dioxide yields this type of transfer at all usable welding currents above the short-circuiting range.
Globular transfer is characterized by an irregular drop size approximately 2 to 4 times the diameter of the electrode.
The mechanism producing globular transfer is generated in a specific current and voltage range.
With carbon dioxide, the droplet is not propelled across the arc.
The droplet surface tension and the repelling force of the arc acting toward the wire end tends to hold the droplet on the end of the wire until it transfers by gravity.

***Spray Transfer Mode.***

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

***Molten metal transfers across the arc as small droplets.
The metal transfer is axially directed to the work piece.
Since the metal droplets are small, the transfer rate can be as high as several hundred droplets per second.***

***Pulsed Spray Transfer Mode.***

In the pulsed spray transfer mode, the current is cycled between a high and low value at a rate of up to several hundred cycles per second. The low level current is below the spray transition current, while the high current pulse is above the spray transition current.

Metal is transferred to the work piece only during the high current pulse.

Ideally, one small droplet is transferred during each pulse. The rate of pulsing can vary depending on the power supply design and control circuitry. The background current maintains the arc.

The resulting lower average current levels and heat input allow for all-position welding of base metals less than 1/8 in. [3 mm] thick with a spray-type metal transfer mode.

***High-Current-Density Spray Transfer Mode.***

High-current-density spray transfer is a name given to a GMAW mode having specific arc characteristics created by a combination of wire feed speed, electrode extension, and shielding gas.

Mixtures of argon with oxygen and/or carbon dioxide are most popular for carbon steel and low alloy steel electrodes.

Filler metal deposition rates range between 18 lb/hr and 30 lb/hr [8 and 14 kg/hr] with an upper limit of 40 lb/hr [18 kg/hr].

The arc characteristics of highcurrent-density transfer are further divided into rotational spray transfer and non-rotational spray transfer modes.

***(1) High-Current-Density Rotational Spray Transfer Mode.***

When using a solid carbon steel wire, a high wire feed speed is combined with a long electrode extension to create an arc known as rotational spray arc transfer. The long contact tube to work piece distance produces resistance heating of the wire electrode and causes the electrode end to become molten.

The electro-magnetic forces generated by the current flow in the wire cause the molten wire end to rotate in a helical path.

The shielding gas affects the rotational transition current by changing the surface tension at the molten electrode end.

Gas mixtures of argon, carbon dioxide, oxygen can produce rotational spray transfer deposition rates of 181b/hr to 30 lb/hr [8 kg/hr to 14 kg/hr] using contact tip to work piece distance of 7/8 in. to 1-1/2 in. [22 mm to 38 mm].

***(2) High-Current-Density Non-Rotational Spray Transfer Mode.***

Non-rotational highcurrent-density spray transfer is produced when the molten wire end does not rotate.

Rotation is suppressed when the thermal conductivity of the shielding gas increases and the surface tension of the molten electrode end increases. The droplet rate will decrease, and larger droplets will transfer across the arc.

Shielding gases with higher carbon dioxide or helium additions will raise the rotational spray transition current, thereby suppressing the tendency to rotate.

The arc is elongated and diffused but looks similar to conventional spray transfer.

The plasma stream is axial and narrower than that produced by rotational spray transfer.

This more concentrated heat source can produce an increased depth of fusion compared with rotational spray transfer at the same welding current.

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# Recommended Gases for Welding

## *Gas Selection for Gas Metal Arc Welding* *[Table 2]*

| Metal | Type Thickness | Transfer Mode | Recommended Shielding Gas | AWS Designation per A5.32 | Advantages / Description |
|---|---|---|---|---|---|
| Carbon Steel | Up to 14 gauge Or 0.064 in. [1.6 mm] | Short Circuit | Argon + 8% $CO_2$<br>Argon + 25% $CO_2$<br>Aegon + 8% $CO_2$ + 2% $O_2$ | SG-AC-8<br>SG-AC-25<br>SG-ACO-8/2 | Good depth of fusion and distortion control to reduce potential burn-through. |
| | 14 gauge or 0.064 in. to 1/8 in. [1.6 mm to 3 mm] | Short Circuit | Argon + 8% $CO_2$<br>Argon + 25% $CO_2$<br>Argon + He + $CO_2$ | SG-AC-8<br>SG-AC-25<br>SG-AHeC-G | Higher deposition rates without burn-through. Minimum distortion and spatter.<br>Good weld pool control for out of position welding. |
| | Over 1/8 in. [3 mm] | Short Circuit | 100% $CO_2$<br>Argon + 15% $CO_2$<br>Argon + 18% $CO_2$<br>Argon + 25% $CO_2$ | SG-C<br>SG-AC-15<br>SG-AC-18<br>SG-AC-25 | High welding speed.<br>Good depth of fusion and puddle control.<br>Applicable for out-of position welding. |
| | | Short Circuit or Globular | Argon + 25% $CO_2$ | SC-AC-25 | Suitable for high current & high speed welding. |
| | | Short Circuit | Argon + 50% $CO_2$ | SC-AC-50 | Deep depth of fusion; low spatter: high travel speeds. Good out-of position welding. |
| | | Short Circuit or Globular (buried arc) | 100% $CO_2$ | SG-C | Deep depth of fusion and fastest travel speeds but with higher melt-through potential. High current mechanized welding. |
| | | Spray Transfer | Argon + 1% $O_2$<br>Argon + 2% $O_2$<br>Argon + 5% $O_2$<br>Argon + 8% $O_2$ | SG-AO-1<br>SG-AO-2<br>SG-AO-5<br>SG-AO-8 | Good arc stability; produces a more fluid puddle as O, increases: good coalescence & bead contour. Good weld appearance & weld pool control. |
| | | Spray Transfer | Argon + 5% $CO_2$<br>Argon + 8% $CO_2$<br>Argon + 10% $CO_2$<br>Argon + 20% $CO_2$ | SG-AC-5<br>SG-AC-8<br>SG-AC-10<br>SG-AC-20 | Fluid weld pool and oxidizing to weld metal causing higher amounts of slag and scale, as CO, increases.<br>Good arc stability, weld soundness, and increasing width of fusion. |
| | | Short Circuit | Argon + 8% $CO_2$ + 2% $O_2$ | SG-ACO-8/2 | Applicable to both short-circuiting and spray transfer modes. |
| | | Spray Transfer | Argon + 35% Helium + 1% $CO_2$<br>Helium + 43% Argon + 2% $CO_2$ | SG-AHeC-35/ 1<br>SG-HeAC-43/2 | Has a wide welding current range and good arc performance.<br>Weld pool has good control which results in improved weld contour. |
| | | High-Current-Density | Argon + Helium + $CO_2$ + O<br>Argon + $CO_2$ + $O_2$ | SG-AHeCO-G<br>SG-ACO-G | Used for high deposition rate welding where 15 lb/hr to 30 lb/hr [7 kg/hr to 14 kg/hr] is typical. Special welding equipment and techniques are sometimes required to achieve these deposition levels. |
| | Over 14 gauge or 0.064 in. [ 1.6 mm] | Pulsed Spray | Argon + 2% to 8% $O_2$<br>Argon + 5% to 20% $CO_2$<br>Argon + 8% $CO_2$ + 2% $O_2$<br>Argon +Helium + $CO_2$ | SG-AO-2 to 8<br>SG-AC-5 to 20<br>SG-ACO-8/2<br>ST-AHeC-G | 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 On Next Page)*

# Recommended Gases for Welding

## *Gas Selection for Gas Metal Arc Welding* *[Table 2]*

| Metal | Type Thickness | Transfer Mode | Recommended Shielding Gas | AWS Designation per A5.32 | Advantages / Description |
|---|---|---|---|---|---|
| Low & High-Alloy Steel | Up to 3/32 in. [2 mm] | Short Circuit | Argon + 8% to 20% $O_2$<br>Helium + Argon + $CO_2$<br>Argon + 8% $CO_2$ +2% $O_2$ | SG-AC-8 to 20<br>SG-HeAC-G<br>SG-ACO-8/2 | Good coalescence and bead contour. Good mechanical properties. |
| | | Short Circuit | Argon + 20% to 50% $CO_2$ | SG-AC-20 to 50 | High welding speeds. Good depth of fusion and weld pool control. Applicable for out-of position welds. Suitable for high current and high-speed welding. |
| | Over 3/32 in. [2 mm] | Spray (Including High-Current-Density Rotational and Non-Rotational) | Argon + 2% $O_2$<br>Argon + 5% $CO_2$<br>Argon + 8% $CO_2$<br>Argon + 10% $CO_2$<br>Argon + 8% $CO_2$ + 2% $O_2$<br>Argon + Helium + $CO_2$ + $O_2$ | SG-AO-2<br>SG-AC-5<br>SG-AC-8<br>SG-AC-10<br>SG-ACO-B/2<br>SG-AHeCO-G | Reduces undercutting.<br>Higher deposition rates and improved head wetting.<br>Deep depth of fusion and good mechanical properties. |
| | | Pulsed Spray | Argon + 2% $O_2$<br>Argon + 5% $CO_2$<br>Argon + 8% $CO_2$ + 2% $O_2$<br>Helium + 43%<br>Argon + 2% $CO_2$ | SG-AO-2<br>SG-AC-5<br>SG-ACO-B/2<br>SG-HeAC-43/2 | Used for both light-gauge and heavy out-of-position weldments.<br>Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges. |
| Stainless Steel | Up to 14 gauge or 0.064 in. [2 mm] | Short Circuit | Argon + 2% $CO_2$<br>Argon +5% $CO_2$ | SG-AC-2<br>SG-AC-5 | Good control of burn-through and distortion. Used also for the spray transfer mode. Weld pool fluidity is sometimes sluggish, depending on the base alloy. |
| | Over 14 gauge or 0.064 in. [2 mm] | Short Circuit | Helium + 7.5%<br>Argon + 2.5% $CO_2$<br>Argon + 2% to 5% $CO_2$<br>Argon + Helium + $CO_2$<br>Helium + 43%<br>Argon + 2% $CO_2$ | SG-HcAC-7.5/2.5<br>SG-AC-2 to 5<br>SG-AHeC-G<br>SG-HeAC-43/2 | Low $CO_2$ percentages in helium mix minimizes carbon pickup, which can cause inter-granular corrosion with some alloys.<br>Helium improves bead wetting action and contour. $CO_2$ percentages over 5% should be used with caution on some alloys.<br>Applicable for all position welding. |
| | | Spray | Argon + 1% $O_2$<br>Argon + 2% $O_2$<br>Argon + Helium + $CO_2$<br>Helium + Argon + $CO_2$ | SG-AO-1<br>SG-AO-2<br>SG-AHeC-G<br>SG-HeAC-G | Good arc stability. Produces a fluid but controllable weld pool; good coalescence and head contour. Minimizes undercutting on heavier thicknesses. |
| | Over 14 gauge or 0.064 in. [2 mm] | Pulsed Spray | Argon + 1% $O_2$<br>Argon + 2% $O_2$<br>Argon + Helium + $CO_2$<br>Helium + Argon + $CO_2$<br>Argon + $CO_2$ + $H_2$ | SG-AO-1<br>SG-AO-2<br>SG-AHeC-G<br>SG-HcAC-G<br>SG-ACH-G | Used for both light- and heavy-gauge out-of-position weldments.<br>Achieves good pulse spray stability over a wide range of arc characteristics and deposition ranges. |

*(Continued On Next Page)*

# Recommended Gases for Welding

## *Gas Selection for Gas Metal Arc Welding [Table 2]*

| Metal | Type Thickness | Transfer Mode | Recommended Shielding Gas | AWS Designation per A5.32 | Advantages / Description |
|---|---|---|---|---|---|
| Nickel, Nickel Alloys, Copper & Copper Alloys | Up to 1/8 in. [3 mm] | Short Circuit | Helium + 10% Argon<br>Helium + 25% Argon<br>Argon + Helium | SG-HeA-10<br>SG-HeA-25<br>SG-AHe-G | Good arc stability, weld pool control and wetting. |
| | Over 1/8 in. [3 mm] | Spray | Argon + Helium<br>Argon + 50% Helium<br>Argon or Helium | SG-AHe-G<br>SG-AHe-50<br>SG-A or SG-He | Higher heat input of helium mixtures offset high heat conductivity of heavier gauges. Good wetting and bead contour. Can be used for out-of-position welding.<br>Using 100% helium on heavier material thickness improves bead wetting and depth of fusion. |
| | | Pulsed Spray | Helium + Argon | SG-HeA-G | Good out-of-position control. |
| Aluminum | Up to 1/2 in. [13 mm] | Spray or Pulsed Spray | Argon | SG-A | Best metal transfer, arc stability and plate cleaning. Little or no spatter. Removes oxides when used with DCEP (Reverse Polarity). |
| | Over 1/2 in. [13 mm] | Spray or Pulsed Spray | Helium + 25% Argon<br>Argon + 50% Helium<br>Argon 100%<br>Helium 100% | SG-HeA-25<br>SG-AHe-50<br>SG-A<br>SG-He | High-heat input.<br>Produces fluid puddle, flat bead contour and deep depth of fusion.<br>Minimizes porosity. |
| Magnesium, Titanium & other Reactive Metals | All Thicknesses | Spray | Argon | SG-A | Excellent cleaning action.<br>Provides more stable arc than helium-rich mixtures. |
| | | Spray | Argon + 30% Helium<br>Argon + 50% Helium<br>Helium + 25% Argon | SG-AHe-30<br>AG-AHe-50<br>SG-HeA-25 | Higher heat input and less chance of porosity.<br>More fluid weld pool and improved wetting. |

## *Argon (SG-A).*

Argon is a chemically inert gas that is used alone and in combination with other gases for welding both ferrous and nonferrous metals.
All GMAW modes can use argon or argon mixes to achieve good weldability, required mechanical properties, stable arc characteristics, and improved productivity.
The low ionization potential of argon helps create an excellent current path and superior arc stability.
Argon produces a constricted arc column with high current density, which causes the arc energy to be concentrated over a small surface area.
The result is a depth of fusion profile with a distinct finger like shape as shown in diagram.
Argon is used for nonferrous base metals such as aluminum, nickel, copper, and magnesium alloys, as well as for reactive metals such as zirconium and titanium.
Argon and argon mixes provide spray transfer with excellent arc welding stability, penetration and bead profile.
When welding ferrous base metals, argon is usually mixed with other gases such as oxygen, helium, and carbon dioxide.

## *Carbon Dioxide (SG-C).*

Carbon dioxide is a chemically active gas.
In the presence of an intense heat source such as a welding arc, it associates into carbon monoxide and free oxygen and becomes active.
This is shown by the following equation: $CO_2 \rightarrow CO_2 + O$
The free oxygen, which is available in considerable amounts, reacts with other elements in the weld pool.
Although carbon dioxide is an active gas and produces an oxidizing effect, sound welds can be consistently achieved.
Carbon dioxide is often used for welding carbon steel.
Its popularity is due to common availability, low cost, and weld performance.
The low cost per unit of gas does not automatically translate to lowest cost per foot of deposited weld.
Total weld cost with carbon dioxide shielding gas is influenced by bead contour, electrode spatter, and spatter removal.
Carbon dioxide, by itself, will not support spray transfer.
Metal transfer is restricted to short-circuiting and globular transfer.
The advantage of carbon dioxide is its increased depth of fusion compared to argon.
The major disadvantage of carbon dioxide is harsh globular transfer with its characteristic spatter at elevated weld currents.
The weld surface resulting from using a 100% carbon dioxide shielding gas is usually heavily oxidized.
A welding wire having higher amounts of deoxidizing elements may be needed to compensate for the reactive nature of the gas.
Overall, good mechanical properties can be achieved with carbon dioxide.

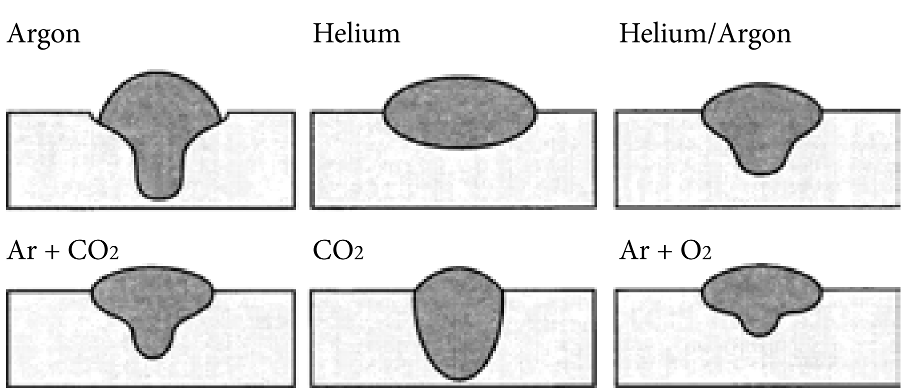


Figure 1. Typical GMAW Bead & Penetration Profiles with Several Shielding Gases

*Helium (SG-He).*

Helium is a chemically inert gas used for welding applications requiring higher heat inputs.
Helium may improve wetting action, width of fusion and travel speeds.
It does not produce the stable arc provided by argon.
Helium has higher thermal conductivity than argon and a wider arc column.
The higher voltage gradient increases heat input compared with argon, promoting increased weld pool fluidity and better wetting action.
This is an advantage when welding aluminum, magnesium, and copper alloys.
Helium is often mixed with argon to obtain the advantages of both gases.
Argon provides good arc stability and cleaning action, while helium promotes wetting with a broad width of fusion.

## *Two-Component Shielding Gas Mixtures (see previous Table)*

*Argon + Oxygen (SG-AO).*

The addition of small amounts of oxygen to argon greatly stabilizes the welding arc, increases the filler metal droplet transfer rate, lowers the spray transition current and influences bead shape when welding steels.
The weld pool is more fluid and stays molten longer, allowing the metal to flow out toward the toe of the weld.
Argon oxygen mixtures produce a narrow deep penetration pattern that could be susceptible to porosity entrapment during rapid weld pool cooling.
Slower travel speeds reduce weld pool cooling rates and minimize porosity entrapment.
Argon-oxygen shielding gas mixtures are available pre-blended in liquid form.

*(1) Argon + 1% Oxygen (SG-AO-1).*

This mixture is primarily used for spray transfer on stainless steels.
One percent oxygen is usually sufficient to stabilize the arc, increase the droplet rate and improve bead appearance.

*(2) Argon + 2% Oxygen (SG-AO-2).*

This mixture is used for spray arc welding on carbon steels, low alloy steels, and stainless steels.
It provides additional wetting action over the 1% oxygen mixture.
Mechanical properties and corrosion resistance of welds made with 1% and 2% oxygen additions are equivalent.

*(3) Argon + 5% Oxygen (SG-AO-5).*

This mixture provides a more fluid, but still controllable, weld pool and permits higher travel speeds.
It is the most commonly used argon and oxygen mixture for carbon steel welding.

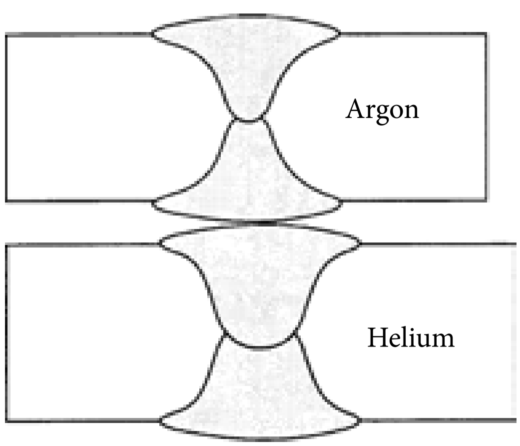


Figure 2.
The Effect of Argon & Helium Shielding Gases on Bead Profile & Penetration when Welding Aluminum with GMAW

## *Argon + Carbon Dioxide Mixtures (SGAC).*

The argon + carbon dioxide mixtures are used mainly on carbon and low alloy steels and have limited application on stainless steels.
Carbon dioxide additions to argon allow increased travel speeds with greater depth and width of fusion.
With these mixtures, increasing the amount of carbon dioxide will result in an increase in the level of spatter and a decrease in deposition efficiency.
In GMAW with carbon dioxide additions, a slightly higher current level must be provided in order to establish and maintain stable spray transfer.
Above approximately 20% carbon dioxide, spray transfer becomes unstable and periodic short-circuiting and globular transfer occurs.

### *(1) Argon + 2% to 10% Carbon Dioxide (SG-AC-2, SG-AC-5, SG-AC-8, SG-AC-10).*

These mixtures are used for spray, pulse spray and short-circuiting transfer on a variety of material and thickness.
Argon with 2% carbon dioxide is a common mixture for pulse welding stainless steel.
A 5% carbon dioxide mixture may be used for pulsed GMAW of low alloy steels being welded in other than the flat position.
With 5% to 10% carbon dioxide, the arc column is constricted.
The arc forces that develop give these mixtures more tolerance to mill scale with a controllable weld pool.

### *(2) Argon + 15% to 20% Carbon Dioxide (SG-AC-15, SG-AC-18, SG-AC-20).*

This mixture range has been used for a variety of applications on carbon and low alloy steels.
Maximum productivity on thin base metals can be achieved within this range.
This is done by minimizing excessive melt-through tendency by increasing deposition rates and travel speeds.
The lower carbon dioxide percentages also improve deposition efficiency by decreasing spatter loss.

### *(3) Argon + 21% to 49% Carbon Dioxide (SG-AC-21 to 49).*

This range is commonly used for GMAW with the short circuit transfer mode on low-carbon steel.
It was formulated to provide maximum short-circuiting frequency in the short circuit transfer mode with common welding electrode sizes.
These mixtures operate well in high current applications on thick base metal.
They promote good arc stability, weld pool control and weld bead appearance

### *(4) Argon + 50% Carbon Dioxide (SGAC-50).*

This mixture is used where high heat inputs and increased fusion depth are needed.
Recommended base metal thickness is above 1/8 in. [3 mm].
Fusion is increased in welding positions other than flat when utilizing the short-circuiting transfer mode.
Good wetting and bead shape, without excessive fluidity, are the main advantages for pipe welding applications.
Welding on thin-gauge materials with this mixture may produce excessive melt through.
When welding at high current levels, the metal transfer is similar to welding in 100% carbon dioxide.
Some reduction in spatter is realized (in comparison to 100% $CO_2$) due to the argon content.

# Recommended Gases for Welding

***Argon + Helium (SG-AHe).***

Argon and helium mixtures are used primarily for welding nonferrous and reactive metals, such as aluminum, copper, nickel, magnesium, and their alloys.
They are also used for welding some carbon steels.
Helium is added to argon to take advantage of the best operating characteristics of each gas.
Generally, the thicker the base metal, the higher the percentage of helium.
The addition of helium to an argon base gas will increase the heat input.
Small percentages of helium, as low as 10%, will affect the arc characteristics.
As helium percentages increase, the arc voltage, spatter, and weld depth-to-width ratio will increase (see figure 1 & 2), while porosity is minimized.
The argon content must be at least 45% when mixed with helium to produce and maintain a stable spray transfer mode.

***(1) Argon + 25% to 50% Helium (SGAHe-25, SGAHe-50).***

These mixtures are used for welding nonferrous base metals when an increase in heat input is sought and weld bead appearance is of primary importance.

***(2) Helium + 25% to 50% Argon (SGHeA-25, SGHeA-50).***

These mixtures further increase heat input in comparison to the mixtures having higher argon content.
They are used for welding of aluminum and magnesium greater than 1/2 in. [13 mm] thick in the flat position.
They increase heat input and reduce porosity of welds in copper, aluminum, and magnesium

***(3) Helium + 10% to 25% Argon (SGHeA-10 to 25).***

These mixtures are used for welding copper over 1/2 in. [13 mm] thick and aluminum over 3 in. [75 mm] thick.
Their high-heat input improves weld fusion.
They may be used for short-circuiting transfer with nickel filler metals.

## *Three-Component Shielding Gas Mixtures (see previous Table)*

### *Argon + Carbon Dioxide + Oxygen (SGACO).*

Mixtures containing these three components are versatile due to their ability to function with processes using short circuit, globular, spray, pulsed, and high current-density spray transfer.
Several three component mixtures are available and their application will depend on the desired metal transfer modes.
The advantage of these mixtures is their ability to shield carbon steel and low alloy steel of all thickness using any type of metal transfer mode.
These mixtures produce good welding characteristics and mechanical properties on carbon and low alloy steels.
On thin base metals, the oxygen constituent improves arc stability at low current levels (30 A to 60 A), permitting the arc to be kept short and controllable.
This helps minimize excessive melt-through and distortion by lowering the total heat input in the weld zone.

### *Argon + Helium + Carbon Dioxide (SGAHeC).*

Helium and carbon dioxide additions to argon increase the heat input to the weld, increasing bead wetting and fluidity.
The weld bead profile becomes flatter and wider.

#### *(l) Argon + 10% to 40% Helium + 1% to 15% Carbon Dioxide.*

Mixtures in this range have been developed for pulse spray arc welding of carbon. low alloy, and stainless steels.
These mixtures are most often used on thick sections and in positions other than flat.
Good mechanical properties and weld pool control are characteristic of these mixtures.

#### *(2) Helium + 25 % to 35 % Argon and 1% to 5% Carbon Dioxide.*

These mixtures are used for the short-circuiting transfer mode in welding of high strength and stainless steels, especially for welding positions other than flat.
The carbon dioxide content is kept low to insure good weld metal toughness.
The helium provides the heat necessary for good weld pool fluidity.

#### *(3) Helium + 7.5% Argon + 2.5% Carbon Dioxide (SG-HeAC-7.5/2.5).*

This mixture is widely used for the short circuit transfer mode in welding of stainless steel in all welding positions.
The carbon dioxide content is kept low to minimize carbon absorption and assure good corrosion resistance, especially in multipass welds.
The argon + carbon dioxide additions provide good arc stability and increased depth of fusion.
The high helium content provides significant heat input to overcome the sluggish nature of the stainless steel weld pool.

### *Argon + Helium + Oxygen (SGAHeO).*

Just as the addition of helium to argon increases the arc energy when welding nonferrous metals with the GMAW process, oxygen affects the arc characteristics when welding ferrous metals.
Argon-helium-oxygen mixtures have been used occasionally with spray transfer to increase weld pool fluidity, control bead shape and reduce porosity.

### *Argon + Nitrogen + Oxygen (SGANO).*

Small amounts of nitrogen (1.0% to 3.0%) have been added to argon + 1% oxygen to achieve a completely austenitic microstructure in welds made with Type 347 stainless steel filler metal.

***Four-Component Shielding Gas Mixtures (see previous Table)***

***Argon + Helium + Carbon Dioxide + Oxygen (SG-AHeCO).***
Commonly known as a "quad mix;" this combination is most popular for high-deposition GMAW using the high-current-density metal transfer mode.
This mixture will give good mechanical properties and operability throughout a wide range of deposition rates.
Its major application is welding low-alloy, high-tensile-strength base materials, but it has also been used on mild steel for high productivity welding.
Weld economics are an important consideration in using this gas for welding mild steel.

## *Flux Cored Arc Welding*

***Process Description.***
Flux cored arc welding (FCAW) is an arc welding process that produces coalescence of metals by heating them with an are between a continuous flux-cored metal electrode and the weld pool.
Shielding is provided by either the decomposition of the flux contained within the electrode or externally supplied gas or both.

***Shielding Gases***

***Carbon Dioxide (SG-C).***
Welding with carbon dioxide shielding gas is generally characterized by a globular metal transfer mode.
The oxidizing characteristic of carbon dioxide is well known to the developers and manufacturers of flux cored electrodes.
Deoxidizing materials are added to the core of the electrode to compensate for the oxidizing effect of the carbon dioxide.
The deoxidizing elements have a great affinity for oxygen and readily combine with it.

***Gas Mixtures.***
The trend toward using smaller diameter welding electrodes to obtain greater versatility has resulted in the use of more gas mixtures.
The most common mixture for FCAW is argon + 25% carbon dioxide.
Because of the poor transfer of deoxidizing elements in FCAW when using carbon dioxide.
All electrodes designed for use with carbon dioxide are heavily deoxidized.
When these same electrodes are used with gas mixtures utilizing argon based gases, a buildup of manganese, silicon, and other deoxidizing elements may occur.
Welds produced using these mixtures generally have higher strengths but slightly lower ductility than welds made under the same conditions with carbon dioxide.
Many manufacturers provide different FCAW electrodes for use in either 100% carbon dioxide or argon based mixtures.
Three component mixtures such as argon + carbon dioxide + oxygen have been used with good results with certain HSLA materials.

***(The following information was provided by AWS C5.10/C5.10M:2003***
***Recommended Practices for Shielding Gases for Welding and Cutting)***

# AWS Filler Metal Specifications by Material & Welding Process

| | OFW | SMAW | GTAW GMAW PAW | FCAW | SAW | ESW | EGW | Brazing |
|---|---|---|---|---|---|---|---|---|
| Carbon Steel | A5.2 | A5.1 | A5.18 | A5.20 | A5.17 | A5.25 | A5.26 | A5.8 A5.31 |
| Low-Alloy Steel | A5.2 | A5.5 | A5.28 | A5.29 | A5.23 | A5.25 | A5.26 | A5.8 A5.31 |
| Stainless Steel | - | A5.4 | A5.9 A5.22 | A5.22 | A5.9 | A5.9 | A5.9 | A5.8 A5.31 |
| Cast Iron | A5.15 | A5.15 | A5.15 | A5.15 | - | - | - | A5.8 A5.31 |
| Nickel Alloys | - | A5.11 | A5.14 | - | A5.14 | - | - | A5.8 A5.31 |
| Aluminum Alloys | - | A5.3 | A5.10 | - | - | - | - | A5.8 A5.31 |
| Copper Alloys | - | A5.6 | A5.7 | - | - | - | - | A5.8 A5.31 |
| Titanium Alloys | - | - | A5.16 | - | - | - | - | A5.8 A5.31 |
| Zirconium Alloys | - | - | A5.24 | - | - | - | - | A5.8 A5.31 |
| Magnesium Alloys | - | - | A5.19 | - | - | - | - | A5.8 A5.31 |
| Tungsten Electrodes | - | - | A5.12 | - | - | - | - | - |
| Brazing Alloys & Fluxes | - | - | - | - | - | - | - | A5.8 A5.31 |
| Surfacing Alloys | A5.13 A5.21 | A5.13 A5.21 | A5.13 A5.21 | - | - | - | - | - |
| Consumable Inserts | - | - | A5.30 | - | - | - | - | - |
| Shielding Gases | - | - | A5.32 | A5.32 | - | - | A5.32 | - |

- OFW - Oxyfuel Gas Welding
- SMAW - Shielded Metal Arc Welding
- GTWA - Gas Tungsten Arc Welding (TIG)
- GMAW - Gas Metal Arc Welding (MIG)
- PAW - Plasma Arc Welding
- FCAW - Fluxed Core Arc Welding
- SAW - Submerged Arc Welding
- ESW - Electro Slag Welding
- EGW - Electro Gas Welding