What is the Best MIG Shielding Gas?

By: Jerry Uttrachi, President WA Technology

Answer:

For welding steel and most stainless steel there is *"one gas mixture that is best!"*

We'll start by telling you what it is and providing a quick review of why we use it. It's a tri-mix of Argon, Carbon Dioxide and Oxygen. The specific mixture is 90% Argon, 8% CO_2 and 2% O_2.

Appendix A provides details of why and how that *"universal"* gas mixture was developed. Even some shielding gas suppliers don't understand the reasons or benefits? This report also provides a great deal of information on many MIG shielding gases and mixtures, along with their advantages and shortcomings.

Why Should You Listen to Me?

We're not affiliated with any gas company or gas/welding distributors! In fact, we've sold over 15,000 of our patented Shielding Gas Saving Product directly over the Internet or by word of mouth! More on that later. I started my welding career over 50 years ago in the one of largest welding R&D Labs of a company, Linde, which at that time produced about half the country's Argon. (*Over 150 employees were in our welding R&D lab.*) When the Lab was split in three, I became Manager of the Materials Technology Lab in OH developing welding gases and filler metals. Then moved to corporate office as Director of Welding Market Development in. When *Linde, who later changed their name to Praxair, now part German Linde AG)* decided to focus on selling gas and divest of the welding filler metals and equipment businesses I became VP Marketing for that new company called L-TEC and subsequently ESAB before starting WA Technology. Over the years, I've been a member of a number of the American Welding Society (AWS) volunteer committees. For 15 years I was a volunteer member of the Board and Executive Board of Directors for the nonprofit AWS. After serving as a Director, then VP for 3 years I was elected the 2007 President. I know why and how shielding gases perform!

Benefits of the Tri-Mix Used in Our Shop:

This mixture provides the same or better quality out-of-position welds as the more common shielding gas, 25% CO_2 75% Argon, sometimes called C25. That mode of metal transfer is called short circuiting or Short Arc. However, the tri-mix also provides a mode of metal transfer that C25 cannot! That mode is called Spray Arc where very fine drops are produced, and the result is very little weld spatter. Spray Arc is a hotter mode and can only be used for downhand welds.

Spray Arc also penetrates much more than Short Arc. Since CO_2 in the tri-mix is kept at a low 8% level it can also be used for some stainless-steel applications. Can't do that with C25 since the high amount of CO_2 will put excess carbon in the weld deposit and cause corrosion, particularly at high temperatures. Compared to similar two-part gas mixtures with similar amounts of CO_2 the 2% O_2 it contains provides a hotter Spray Arc. Today distributors often label their gases with names or numbers and may not even tell their sales folks exactly what they are! You can request a copy of the Safety Data Sheet (SDS) for the gas, which they must supply on request. The SDS should provide the information.

When introduced, this gas mixture was sold for the same price as two-part shielding gas mixtures. Ask the price before purchasing. These unique features mentioned are why it is the gas used in our home shop. Details of why and how it was developed are presented in an Appendix A. The MIG process variants, Spray Arc, Short Arc and Pulsed (spray) Arc are discussed in Appendix B.

What Do the Various MIG Shielding Gases Do?

Shielding gas prevents contamination of the molten weld puddle by the Oxygen, Nitrogen and the Hydrogen (from the water vapor) in the surrounding air.

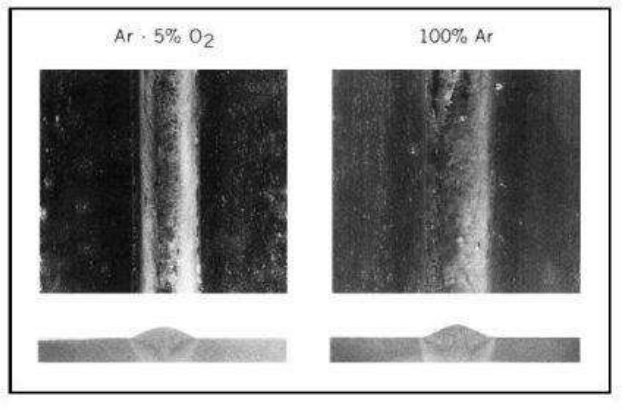
Nitrogen can cause porosity and form brittle nitrides in the weld deposit.

Oxygen combines with carbon to form carbon monoxide gas (CO) porosity. It also forms with other alloying elements like silicon and forms oxide inclusions.

Hydrogen, at even small amounts, causes what is called delayed cracking and sometimes "under bead cracking."

Only pure Argon and Helium are truly 'inert" and will not react with the molten weld. When welding aluminum or titanium they are the only gases that can be used. These two gases have different characterizes, like thermal conductivity, ionization potential, density and other physical factors. These features make one gas provide a more stable arc, hotter weld and wet better into the metal being joined.

Some Early MIG History:



TIG welding was developed on the early 1940's before MIG. Pure Helium or Argon was needed for that process to not only protect the weld but also the tungsten electrode. Even small amounts of Oxygen will contaminate the tungsten electrode in a short time. For MIG, pure Argon or Helium and Argon/Helium mixtures worked well for welding aluminum but when welding steel it was found that to obtain a quality arc and smooth metal transfer, some amount of O_2 or CO_2 needed to be added to the gas mixture.

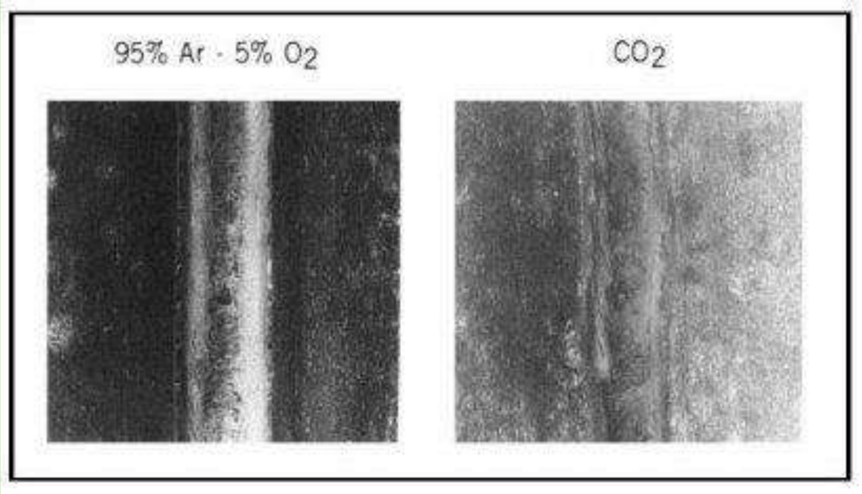
In early developments the only MIG process mode used was Spray Arc, which transfers metal in fine droplets. To get a stable arc, a small amount of O_2, 2% was found ideal. In addition to using the right gas mixture a very small 0.030 diameter wire was used and required a minimum current of 150 amps to produce a stable arc. As mentioned above, the common C25 shielding gas cannot achieve Spray Arc transfer. Our wire plant even had old procedures for making 0.020-inch wire!

If pure Argon is tried with MIG welding steel, the weld will be cold, not wet well into the joint and the arc will not be as stable as when a small amount of reactive gas like O_2 or CO_2 is added.

Common MIG Shielding Gas and Gas Mixtures

Argon is used on non-ferrous materials such as aluminum, nickel-based alloys, copper alloys, and reactive metals like titanium. Some Short Arc welding of very thin materials can also be welded with pure Argon.

Carbon Dioxide forms O_2 and CO in the arc and has an oxidizing effect. However, when welding carbon steel, sound welds can be achieved. Its popularity is due to the common availability and its low cost. It is not produced from the expensive process of liquefying air and distilling, like Argon. It can be produced from waste gas streams in petrochemical production, for example. Since it is stored in the form of a liquid, for a given cylinder size it also holds about twice as much gas at atmospheric temperature and pressure as Argon!



However, as mentioned CO_2 will not produce spray transfer but can be used for Short Arc welding. The major drawback of using pure CO_2 is the harsh globular metal transfer causes high weld spatter levels. The weld surface resulting from pure CO_2 shielding is also more heavily oxidized than when an Argon gas mixture is used. See above figure.

Helium can be used in applications requiring higher heat input for improved bead wetting, deeper penetration and higher travel speed. For MIG it does not produce as stable an arc as Argon. For aluminum MIG welding pure Helium does not give the cleaning action as does pure Argon but the extra heat it provides is beneficial when welding thick sections.

MIG Shielding with Mixes of Two Gases

Argon-Oxygen: The addition of small amounts of O_2 to Argon stabilizes the arc, increases and improves wetting and bead shape. The weld puddle is more fluid and allowing the metal to flow towards the toe of the weld. This reduces undercutting and helps flatten the weld bead.

Argon-2% O_2 – is most commonly used for Spray Arc welding on carbon steels, low alloy steels and some stainless-steel applications. This mixture provides a fluid but controllable weld pool.

Argon-5% O_2 – This mixture provides a more fluid weld pool. The additional oxygen permits welding at higher travel speeds.

Argon-CO_2: These very commonly used mixtures are employed for welding carbon and low alloy steels. The Argon base gas with additions of CO_2 decreases the spatter levels experienced with pure CO_2. Note, above approximately 18 to 20% CO_2 spray transfer becomes unstable and only Short Arc and globular transfer occurs. Therefore, to produce better looking welds and avoid the extra cost of post cleaning considering the post weld costs usually the best choice.

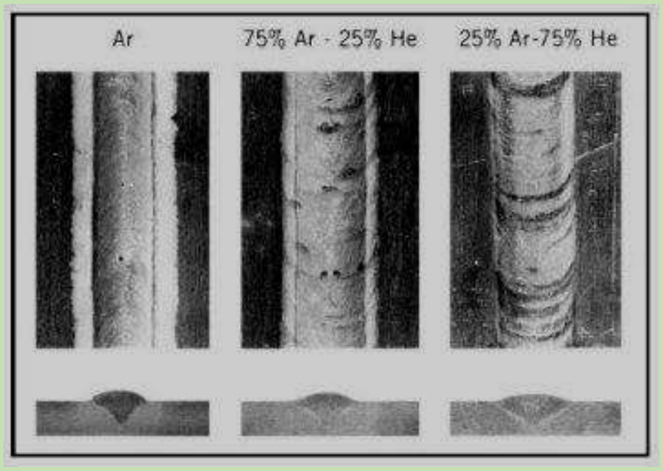
I recall a comment from the welding engineer at John Deere who was very concerned about spatter. He said: *"Our customers pay a premium for our product and don't want small spatter balls popping off with the primer and paint after their first trip in the field and causing rust spots!"*

Argon-5-10% CO_2 – These mixtures are used for Spray Arc and Short Arc metal transfer on a variety of carbon steel thicknesses. Because the mixtures can successfully utilize both Short Arc and Spray arc modes, this gas has gained popularity as a versatile mixture. A 5% mixture is very commonly used for Pulsed Arc MIG welding of heavy section low alloy steels being welding out-of-position. The welds are generally less oxidizing than those with 98 Ar-2% O_2. Improved penetration is achieved with less porosity when using CO_2 additions as opposed to O_2 additions. For improved bead wetting, it requires about twice as much CO_2 to achieve the same wetting as O_2. The arc column with these gas mixtures is very stiff and defined. The strong arc forces that develop give these mixtures more tolerance to mill scale and a very controllable puddle.

Argon-11-20% CO_2 – This mixture range has been used for various narrow gap, out-of-position sheet metal and high speed MIG applications. Most applications are on carbon and low alloy steels. By mixing the CO_2 within this range, maximum productivity on thin gauge materials can be achieved. This is done by minimizing burnthrough potential while at the same time maximizing deposition rates and travel speeds. The lower CO_2 percentages also improve deposition efficiency by lowering spatter loss.

Argon-20-25% CO_2 (C-25) – This range is universally known as the gas used for MIG Short Arc welding of mild steel.

[An interesting anecdote was told to me by a friend and colleague who worked in our R&D Lab developing shielding gases when MIG Short Arc was being developed. Mixed gases in cylinders were not readily available so two gas cylinders were used in experimentation. He said they would set flowmeters on an Argon and CO_2 cylinder and evaluate different mixtures. He found the optimum mixture was 22½ % CO_2 in Argon. Since they were working with the small diameter wires used for MIG Spray Arc, like 0.030-inch OD, 20 CFH gas flow was sufficient for the ½ inch ID nozzles. Because it was easier to have customers set the Argon cylinder flow at 15 CFH and the CO_2 at 5 CFH, 25% CO_2 became the typical recommendation! Of interest Airco, (the other major developer of MIG welding) recommended a mixture of 20% CO_2 in Argon! Perhaps with the current high Argon prices using two cylinders is a way to save some money! But there is an easier, better way to cut your shielding gas cost in half-see Appendix C.]



Argon-Helium: These mixtures are used for welding aluminum, copper, and nickel alloys. These gases are used in various combinations and increase the voltage and heat of MIG as more Helium is added. To maintain better arc stability characteristics a minimum of 20% Argon is needed. Generally, the heavier the material the higher the percentage of Helium. Mixtures typically range from 20 to 75% Helium. The figure left shows weld beads made with several Argon Helium gas mixtures.

MIG Shielding with Mixes of Three Gases

Argon-Oxygen-Carbon Dioxide Mixtures These three components have been termed "universal" mixtures due to their ability to operate using short circuiting, globular, spray, pulse and high-density type transfer characteristics.

Argon-5-10% CO_2 - 1-3% O_2 – This ternary mixture range has gained popularity. The chief advantage is its versatility to weld carbon steel, low alloy steel and stainless steel of all thicknesses utilizing whatever metal transfer type applicable. Carbon pick-up on stainless steel could be an issue on some high temperature applications however if an ELC (extra low carbon) stainless wire is employed using Short Circuiting this should not be a problem. On carbon and low alloy steels, this mixture produces good welding characteristics and mechanical properties. On thin gauge materials, the O_2 assists the arc stability at very low current levels (30 to 60 amps) permitting the arc to be kept short and controllable. This helps minimize burnthrough and distortion by lowering the total heat input into the weld zone. Appendix A reviews the development of the tri-mix we use.

Argon - 10-20% CO_2 - 5% O_2 – This mix produces a hot Short Arc and a fluid puddle. Spray arc transfer is hotter and may provide improved wetting with some carbon steel wires.

Argon-CO_2-Hydrogen Small additions of hydrogen (1-2%) have been shown to improve bead wetting and arc stability when Pulsed MIG welding stainless steel. The CO_2 is also kept low (1-3%) to minimize carbon pick-up and maintain good arc stability. This mixture *<u>should not be used for carbon steel</u>* since excessive weld metal hydrogen could cause weld cracking.

Argon-Helium-CO_2 -Helium and CO_2 addition to Argon increase the heat and improve arc stability. Better wetting and bead profile is achieved.

Argon - 10-30% He - 5-15% CO_2 – Mixtures in this range are used for Pulsed Arc Welding of both carbon and low alloy steel. Best performance is on heavy section, out-of-position applications. Good mechanical properties and puddle control are achieved. Pulse spray arc welding with low average currents is acceptable but mixtures with small CO, and/or O_2, percentages will improve arc stability.

60-70% He - 20-35% Ar - 4-5% CO_2 – This mixture is used for Short Arc welding of high strength steels, especially for out-of- position applications. The CO_2 content is kept low to insure good weld metal toughness. The Helium provides the heat necessary for puddle fluidity. High Helium contents are not necessary, as the weld puddle may become too fluid for easy control.90%

Helium - 7.5% Ar - 2.5% CO_2 – This mixture has been widely used for Short Arc welding of stainless steel in all positions. The CO_2 content is kept low to minimize carbon pickup and assure good corrosion resistance, especially in multipass welds. The CO_2 + argon addition provides good arc stability and penetration. The high Helium content provides extra heat input to overcome the sluggish nature of the stainless-steel weld puddle...

BOTTOM LINE:

If welding carbon steel a tri-mix having 90% Argon- 8% CO_2- 2% O_2 is a good *"universal mix*." If using bulk gas supply or if the cost of the tri-mix is significantly more than a two-gas mix then 8% to 12% CO_2 balance Argon can produce similar results in many applications. Argon 25% CO_2 (C25) is a common MIG gas mixture but is limited to globular transfer typical of Short Arc welding.

References: Much of this information comes from the original "MIG Welding Handbook" our Market Development group produced. It was also printed as an L-TEC document when Linde (renamed Praxair) sold the welding filler metals and cutting and welding equipment businesses. It was later published by ESAB who purchased the L-TEC business.

I have also used the extensive MIG welding shielding gas research information developed over my career and particularly in the past 20 years after forming WA Technology. Much of this can be downloaded as a PDF by clicking the box on the upper right of ever ***www.NetWelding.com*** web page, it contains extensive references.

Appendix A

Development of Stargon

The tri-mx Argon–CO_2–O_2 was developed to make an Argon based gas shielding gas as easy to select and sell as CO_2. I'll explain and use only the first names of those involved (*to protect the innocent!*)

It started in my Director of Market Development role, which was to help fabricators reduce welding cost, increase welding and cutting productivity and to inform them of Argon gas mixture advantages. At the time we had about 50% of the US production capacity of Argon gas. We sold about 30% ourselves as that was our overall gases market share. The other 20% was sold to our industrial gas competitors. We'd fight in the marketplace but business was business! In fact in the Industrial gas business distribution efficiency is most important and transporting liquid gases is a major cost. All competitors would fill up their tank trucks at whosever plant was closest. Then the companies would keep track and *"trade molecules."* For Argon, excess capacity was sold to them at negotiated, wholesale prices!

Visit to Large Distributor:

While visiting with Ron, the sales manager of the large distributor, he mentioned he had just switched a customer from an Argon based gas to CO_2. I asked why and he mentioned they were making out-of-position welds as well as many downhand large welds. He said they only wanted one gas in the shop so CO_2 was a good fit and easy for him to select! We did not sell CO_2 at the time so this was a disturbing comment. How many others were perhaps making the same selection for those reasons? Later I met with the distributor owner, who I knew for many years and I asked about their profitability of selling CO_2 versus Argon based gases. He said, as expected, that Argon gases were significantly more profitable.

Canada Sold Universal Argon Based Shielding Gas:

I spent significant time in Canada in my career including several times per year conducting training courses for our company's sales and sales engineering personnel. During a visit I had heard about a very successful shielding gas promotion called MIG MIX GOLD. I visited with Neil, the regional manager whose region had the most success. I asked what the key success points were and he said *"they did not tell anyone what the mix was*!" His past sales experience was when suggesting a fabricator try a new gas mix, they often would say, *"We tried that before."* If there was no mention of what it was, just a better mix for their applications, they often would try it! They even alluded that it might be a tri-mix. That same two gas mix, sold in the US under our usual generic name, had been tried unsuccessfully! He also thought the catchy name and packaging (they painted the cylinders gold) and attractive literature, was a help.

Appendix A Continued

I was aware from visits to our welding equipment factory in Germany that they were working with some successful tri-mix MIG gases. Several of us in Market Development picked some tri-mix gases to evaluate, and other mixtures were suggested by the engineers at our shielding gas and filler metal Lab. *The objective was having one gas mixture that would make quality Short Arc and Spray Arc welds and performs better than CO_2.* Eight mixes were identified to evaluate. The head of all the companies welding R&D Labs, my old boss Bob, (*a brilliant physicist, who invented plasma welding and cutting*,) had a great idea. He would have the gas mixtures made by the Specialty Gas group and label them A through G. Bob would be the only one knowing which letter was which gas!

After about 3 months of making hundreds of fillet, butt, and mechanical property test welds we met and rated all of them. They were compared with the conventional mixtures such as 2 and 5% Oxygen in Argon and several Argon CO_2 mixtures such as 8, 12, and 25% CO_2. There was a clear winner. The tri-mix of 90% Argon, 8% CO_2, and 2% O_2!

Ad Agency:

We had been using Young and Rubicam, a top NY ad agency. However we did not spend nearly what a P&G does and our account manager was not top notch; *being kind!* I requested for this new product we needed someone better! The company's communications VP suggested a new agency, Poppy Tyson. We were getting Poppy himself, who was impressive. He suggested a radical approach and came up with a new name and promotional campaign. The name he suggested was Stargon! For a very engineering oriented group of folks this would be a major change from the generic C25, O2 etc. gas mixture names historically used in the US. Frankly I was nervous of how well the Stargon name would be received and took steps to see that is was! We advertised it heavily to make fabricators aware there was a new *"kid on the block."*

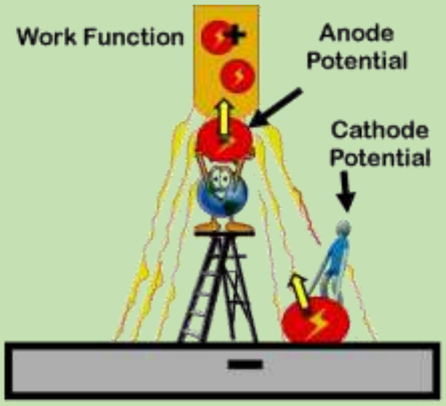
Launch:

The introduction went far better than we expected. I recall one tense moment the night before we were going to divulge the product and Stargon name to 7 sales regions with about 5 persons from each region at a meeting in Westchester County NY. One regional manager of welding engineering, Frank, said he would not support a product if he did not know exactly what it was. I relayed what the SDS said, (*something I had worked hard to get approved by our Safety and Health group*) which was less than 5% O_2, Less than 10% CO_2, balance Argon. Not good enough for him! It was getting late so I said, OK, let's have one more beer and when we're finished if you still want to know, I'll tell you! I then said, *"If you do know the exact composition you'll be in the same position as I am, which is when a good customer and friend asks what it is, I have to say, "I can't tell you."* You have a choice since you have many fabricator friends in the business. "*You can honestly say, you don't know - if you don't or "I won't tell you" or lie!* He thought and said, *"You're right I don't want to know!"* We went to bed!

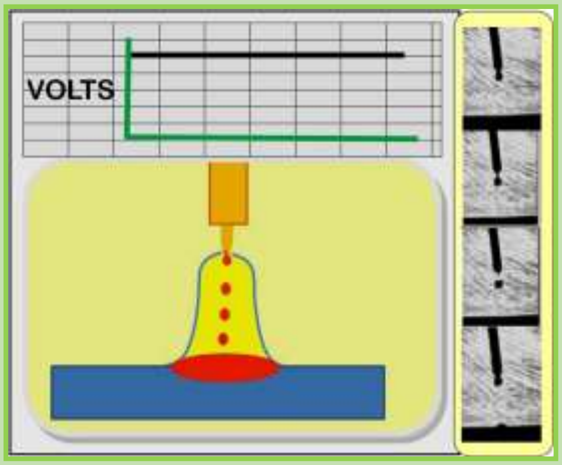
Appendix B

MIG Process Variations:

Getting the molten drops from a MIG wire is not a simple process. When training, I often ask what causes the wire to melt. *It is not the "hot arc" as some mention.* It is the current passing thru the wire as it travels from the contact tip that may heat it to 500+F before the arc. Then the energy it takes to get electrons into the wire surface, called the work function, does the rest. The short time the drops pass thru the arc does not have a significant effect on raising the temperature!

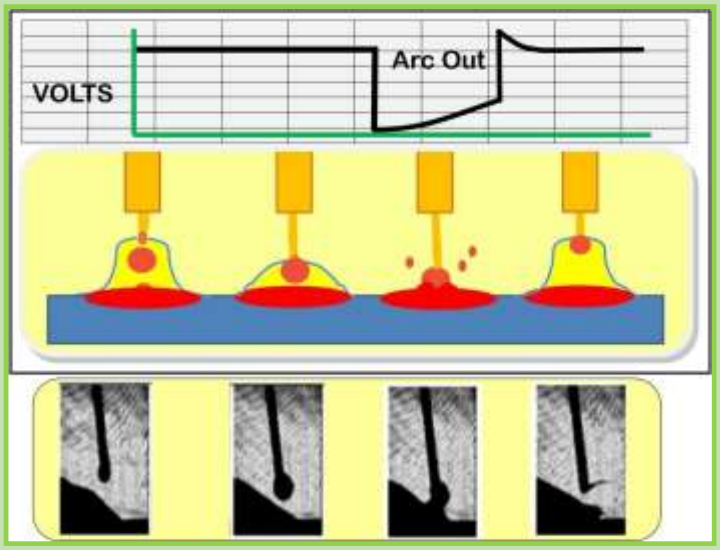


How the arc attaches to the wire tip and drop also has a major affect on the overall arc stability and spatter generation. When MIG was first introduced the welding wires were small diameter, like 0.30 inches or less. The minimum current to achieve a stable arc for a 0.030 diameter wire is about 150 amps. This produces a very hot arc. The drops transfer is a fine stream. This is called Spray Arc.



The figure left shows a simplified electrical voltage trace of a Spray Arc weld. It is very smooth similar to a car battery. In fact some welding machines were made using two car batteries in series! The schematic shows one way the transfer occurs, which is in a fine stream. The accompanying photos are actual high speed pictures of the drops forming and transferring across the arc.

This mode of metal transfer is hot and would make welding out of position very difficult or require very small ID wires. In fact some wires as small as 0.020 inch OD were employed. Tough to feed!



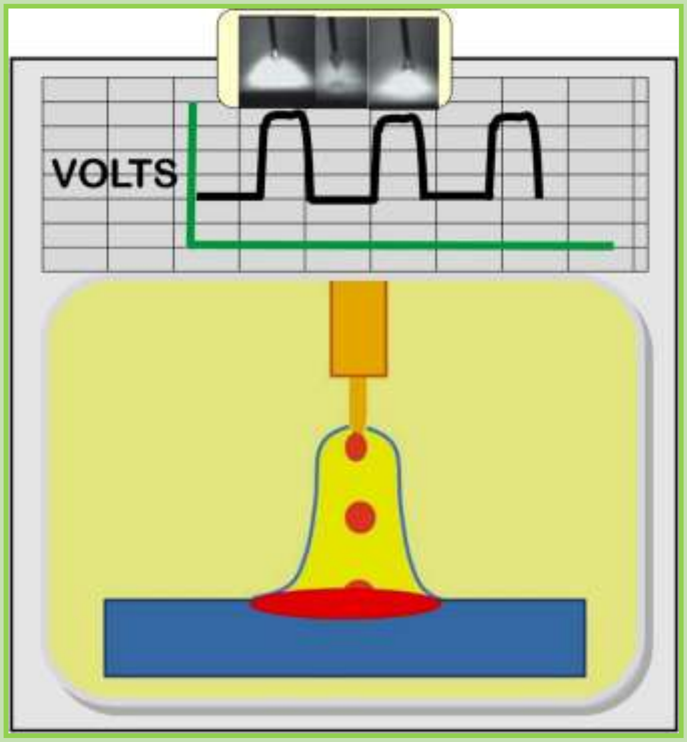
Another metal transfer mode was developed allowing lower metal melting rates and a colder overall arc. This is called Short Arc.

The figure right shows the simplified voltage trace. Unlike in Spray Arc the wire with its molten drop actually shorts to the weld pool.

Appendix B Continued

When that occurs the voltage goes to zero and the current is limited by the power supply design to a relatively low value compared to what can occur in Spray Arc welding if the wire were too short to the puddle. Note in the last arc photo a thin string of metal is projecting to the right. There is a repulsive magnetic force that occurs and it, along with the short circuit inrush current are a cause of spatter.

It took years to develop power supplies that would accomplish this type of control. Typically two extra electrical elements were added to that essentially battery like output. These are slope controls that limit the current when it shorts and the more subtle but most important element, inductance that controls the rate of rise and fall of the current. Some power sources allowed adjusting all three variables. A voltage knob raised and lowered the power supply voltage. A slope control that adjusted the maximum current when the short occurred. A variable inductor that allowed the welder to fine tune the arc and minimize spatter generation. It was not simple to get all these adjusted properly so some were fixed as average levels. Today with fast acting inverters and microprocessors this control can be achieved electronically very quickly using feedback.



The last mode of metal transfer is called Pulsed Arc. It is a Spray Arc but uses variable voltage pulses at a rate of perhaps 100 pulses per second. The high power pulse causes the arc attachment to switch from the drop to the wire and helps cause it to detach. Unlike Short Arc, there is no short of the wire to the puddle. A benefit is you can get a true Spray Arc at much lower currents. This allows the use of larger wires making feeding easier. That is a significant benefit when welding aluminum, for example.

On heavy sections you can weld out of position with almost no spatter and achieve good penetration. Originally this process required very complex power sources, difficult to set and control. Today with high speed inverter and microprocessor technology they are much easier to set and operate.

There is another metal transfer mode called rotary spray but it's more complex than we'll cover here. If interested, email to address below.

 Email Jerry_Uttrachi@NetWelding.com

Appendix C

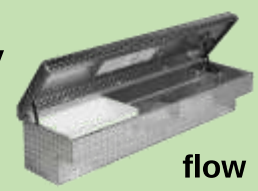
Reducing Shielding Gas Waste, Cost and improving Quality

We mentioned that one way to cut costs is to purchase a cylinder of Argon and one of CO_2 and make your own mix! Somewhat complex and there is a simpler way to save much more. Every time the MIG gun trigger is pulled you can hear the *"gas blast"* exit the nozzle. This is a major cause of wasted gas. Several published articles define that the average MIG welder uses 3+ times the amount of gas needed. In fact one quotes a Praxair engineering representative that indicates their shop surveys show it can be as much as 5 times!

We have invented and patented a system to reduce this *"gas blast"* by about 85% while maintaining the system pressure and enough extra gas to purge the weld start area of air. It's called the *Gas Saver System* (*GSS*™.) It consists of a small ID, very heavy wall, custom extruded gas delivery hose that holds much less gas when welding stops and doesn't expand when the pressure increases. It also contains a peak flow limiting orifice on the welder/wire feeder end so the gas that does exit does so without excess turbulence. It does all this with no moving parts or knobs to adjust. It just replaces the existing gas delivery hose!

How Much Gas Can the *GSS* Save?

Customers provided the following test data and information:



A truck box manufacturer tested the *GSS* and picked a part they weld by the thousands, doors. The found they could weld 236 doors with their standard system and one gas cylinder. Just replacing the gas delivery hose with our *GSS* using the same flow settings they welded 632 doors with one cylinder! That's a 63% savings. Said another way it would have taken 2.7 cylinders with their standard system to weld 632 doors! They purchased 25 *GSS* for all their MIG welders. A year later when installing 10 more MIG welders they called and asked for 10 more *"magic hose!"*

In addition to the "gas blast" at weld starts wasting gas, it also causes air to be pulled into the shielding gas stream. That creates excess spatter and often internal weld porosity. A Caterpillar Tractor facility reported the *GSS*'s they installed eliminated the starting weld porosity they found when X-Raying welds.

Customers typically report savings averaging 40 to 50% of total gas used. There are well over 15,000 *GSS's* in use collectively saving fabricators and small shops millions of dollars each year in gas cost! It also improves weld start quality.

A video entitled "MIG Shielding Gas Control and Optimization" provides more details: http://youtu.be/H5nabh9deLE

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