Explanation for Variations in Charpy Impact Test Results

By Jerry Uttrachi

Fabricators often find significant differences in Charpy impact property test results with the same welding materials, plate and welding parameters. We encountered this situation a number of years ago when exploring significant impact property differences in multipass welds that were made with process procedure variations which should not have produced these differences.

At the time, Dr. Robert Stout from Lehigh University was a consultant to our Welding R&D Laboratory. We employed his suggestion of comparing the impact results with the percent refined versus unrefined weld metal in each Charpy specimen. This approach mostly explained impact value differences for the higher test temperature specimens. But the procedure could not account for the difference of 44 ft-lbs to 8 ft-lbs found in the -50 degree F tests.

Our Senior Metallurgist, Dr. E. C. (Ted) Nelson, postulated a possible reason for these differences. A large multipass weldment was made to avoid issues of plate dilution. Dr. Nelson carefully located Charpy specimens in this weld and duplicated the impact properties producing one specimen with 7 and another with 45 ft-lbs in the exact same weld! This report summarizes of this work.

About the Author

Jerry Uttrachi is President of WA Technology, a company he founded in 1999 dedicated to helping companies improve welding productivity and quality. The Company has patented products and techniques to eliminate shielding gas waste.

Mr. Uttrachi started his career in the welding field 46 year ago in welding R&D at the Linde Division of Union Carbide, a leading company developing welding gases, filler metals and equipment. After managing the companies Material Technology Laboratory developing welding shielding gases and filler metals he became Director of Welding Market Development. When the welding division became a separate company he was named Vice President of Marketing for the newly formed company named L-TEC. He was responsible for Business/Product Management, Marketing, Customer/Technical Service and Communications. When the business was acquired by ESAB in 1989 he remained in that position for the L-TEC brand and for ESAB's Equipment business. In 1999 he left to form WA Technology.

As an active volunteer of The American Welding Society Mr. Uttrachi has served on numerous volunteer committees including recently being on the AWS Board as Director at Large, three years as Vice President and the 2007 President of the Society. He currently is the Chairman of the Societies Education Foundation. He is also a life member of the American Society of Mechanical Engineers where is the Chairman of his local Section.

He holds a Bachelors and Masters degree in Mechanical Engineering and a Masters in Engineering Management from the New Jersey Institute of Technology. He has 9 patents in the welding field, with 4 recent ones related to reducing shielding gas waste and improving weld quality. He has published a number of articles in technical trade publications and journals.

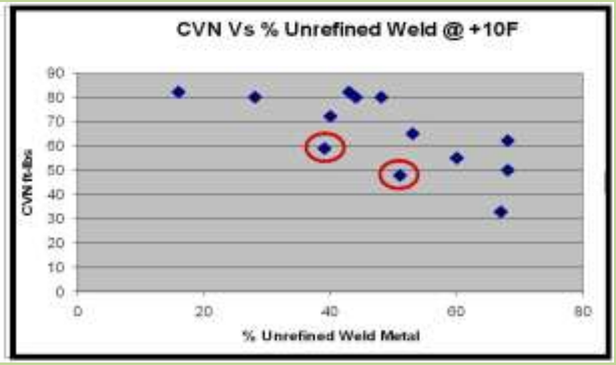
Background

A series of welds were made with three process variations which should not have made a significant difference in weld toughness levels. All welds were made at the same heat input of 87 kj/inch. Weld metal chemistry was nominally; 0.10 C, 1.15 Mn, 0.20 Si and 0.45 Mo. However the impact data was scattered with no consistent pattern as to toughness values even within a process variation. Over 71 Charpy specimens had been produced with statistically adequate duplication.

Dr. Robert Stout was a consultant for our welding R&D Laboratory. He had developed a methodology for explaining differences in Charpy toughness measurements in multipass weldments. The approach examines the area through which the specimens broke by defining the amount of refined versus unrefined weld metal. This is a measure of the area in a previously deposited weld bead that is reheated about 1300 degrees F by a subsequent weld bead. This area, called the heat affected zone (HAZ,) is readily seen with a metallurgical etchant.

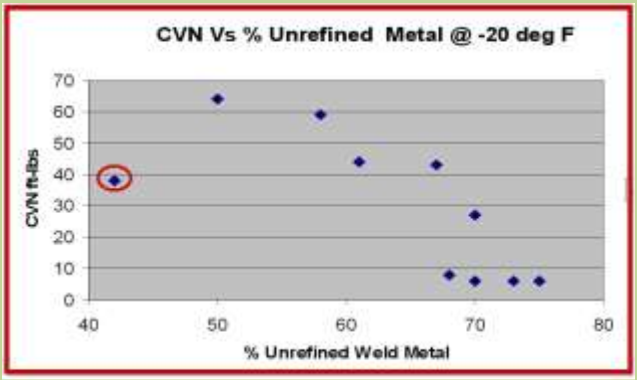
Employing Dr. Stout's Approach

Plotting CVN toughness at +10 degrees F provided the following graph:



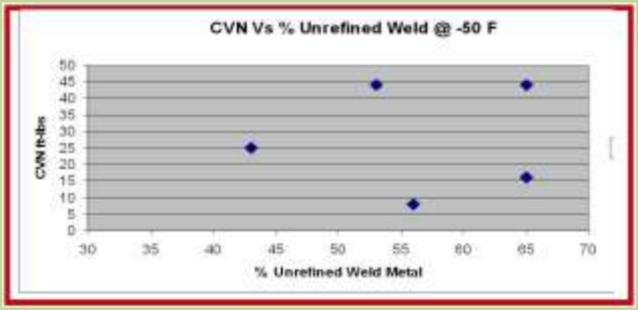
As noted there is reasonable correlation with the toughness and percent unrefined weld metal. Therefore the reheated area (HAZ) of the previous weld bead has a more refined metallurgical structure and higher toughness. There are two anomalies that are circled in red. These points do not provide a good correlation. Tests that will be described subsequently discuss these circled points and explain why they did not provide good correlation.

Plotting CVN toughness at -20 degrees F provided the following graph:



Again there is good correlation with the toughness and percent unrefined weld metal. Therefore the reheated area (HAZ) of the previous weld bead has a more refined metallurgical structure and higher toughness. There is one anomaly that as above will be explained in subsequent tests.

Plotting CVN toughness at -50 degrees F provided the following graph:



Unlike the other two graphs there is no correlation with the -50 degree test data.

Dr. Nelson's Postulate

Dr. Nelson had done all of the metallurgical examination for the determination of the refined versus unrefined material in each Charpy specimen. He had observed several things that caused him to postulate that it was not only the amount of refined material in the specimen but its location that was also significant. As he pointed

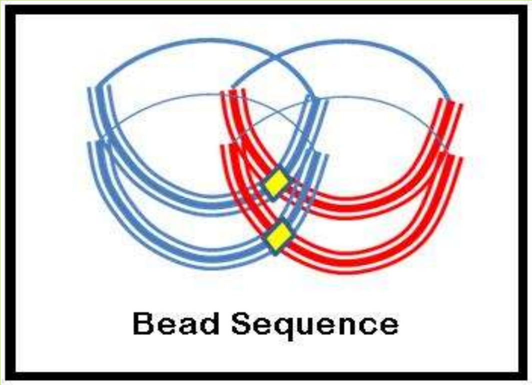
out, a Charpy specimen is subjected to triaxial stresses in the center while the outer edges have only one or two directional stress and strain. In ductile material these outer edges can experience significant deformation. This deformation absorbs a great deal of energy. However even if the center is the exact same material it may have a brittle appearing center because of high triaxial stresses. The picture left illustrates these two zones in this broken Charpy. This was a uniform plate material yet the center fractured easily with little energy required while the outer edges deformed absorbing much more energy. Therefore Dr. Nelson felt that by placing the refined weld metal at the outer edges would result in higher toughness values. Conversely placing the tough refined material in the center was in essence wasting this tough material.

He had also observed that some of the Charpy specimens examined not only had refined material but some was doubly refined. Therefore the heat affected zone of the last weld bead in the sequence was reheating a prior HAZ. This doubly refined material could well be even tougher.

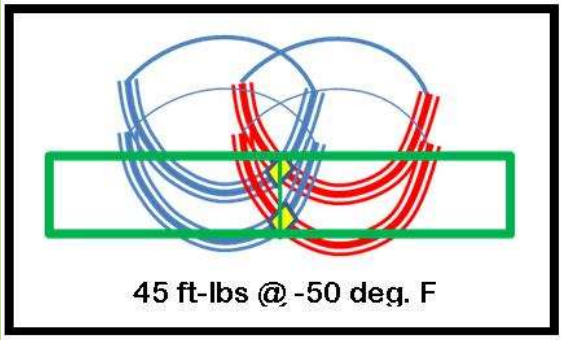
Therefore he asked that we make a large weldment so: 1) there would be no influence of base metal dilution and 2) he could place the Charpy specimens exactly where he wanted. We made a six layer wide by six layer deep weld using a heavy backing bar simulating a thick vessel weld which is what this research work was simulating.

Results of Dr. Nelsons Charpy Placement

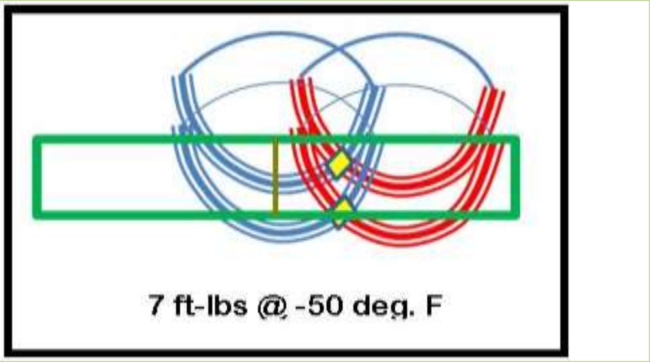
The following pictures depict what was done and the results. These schematics were made from the data and description in Dr. Nelsons report:



This is a representative view of what Dr. Nelson was able to see and then place each Charpy in the desired structure.



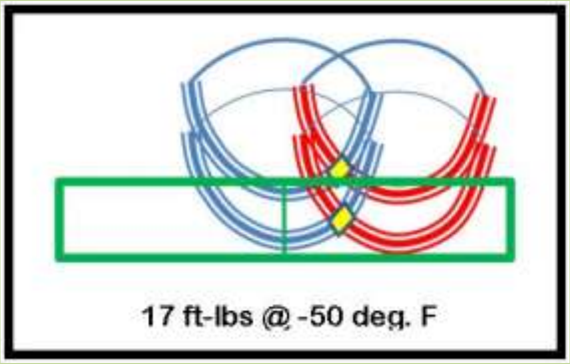
The above schematic shows the toughest Charpy in the series. It had double refined material (yellow area) at both outer edges of the specimen. It matched the 44 ft-lbs found in the previous examinations.



The above schematic shows the lowest toughness specimen produced. It had about 50% single refined material but that was placed in the center of the Charpy specimen or as Dr. Nelson would say most of the refinement was wasted! It matched the 8 ft-lbs in the prior process variations tests!

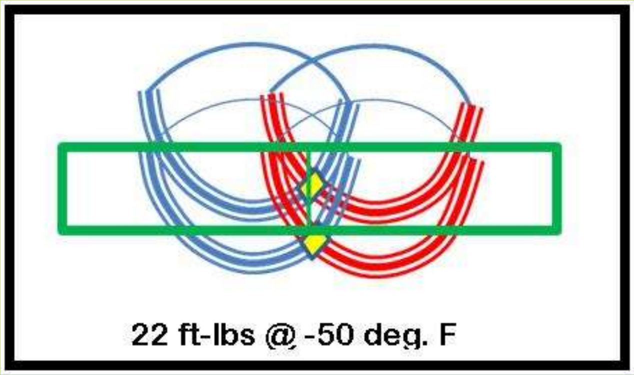
Dr. Nelson made a series of ¾ size Charpys from the weld in attempt to have only the top bead in the broken area. However it was difficult to get exact placements and he concluded the toughness was not much different than the lowest value achieved even with single refined material in the center.

Two other placements are of interest. He located single refined material at the outer edges:



As noted the toughness increased to 17 ft-lbs.

The next test placed doubly refined material in the center of the Charpy specimen:



The toughness was somewhat higher at 22 ft-lbs. In general it does say that in this Mn Mo weld metal the doubly refined material is tougher that single refined material. It clearly shows that when the refined material is placed at the outer edges the toughness is significantly higher.

Back to +10 and -20 deg. F Graphs

Dr. Nelson found that the red circled points in the previous graphs had unrefined material at the outer edges and the refined material somewhat wasted in the center. That was the reason the toughness was lower for the percent refined material they possessed!

APPENDIX

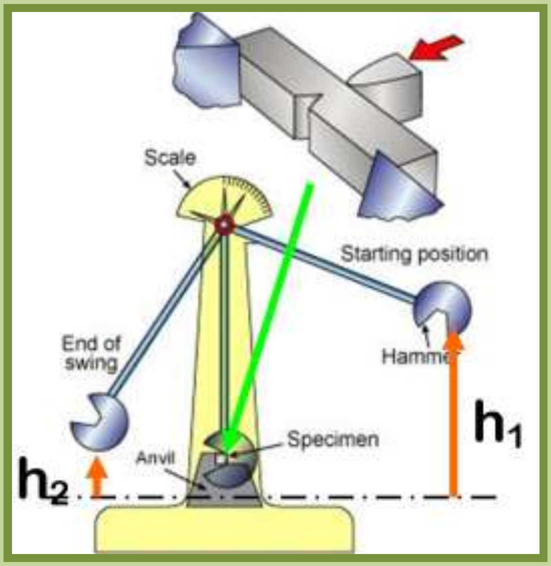
The Appendix provides more information about Charpy testing in general and a brief overview of why steel becomes brittle at lower temperatures.

APPENDIX

Charpy Test

The Charpy test is a good way to measure material toughness. It is useful for materials that exceed the 10 mm (0.394 inches) Charpy height. Specimens can also be made in ¾, and ½ sizes so in theory a 0.20 inch thick specimen can be produced.

The Charpy specimen is relatively easy to make and test.



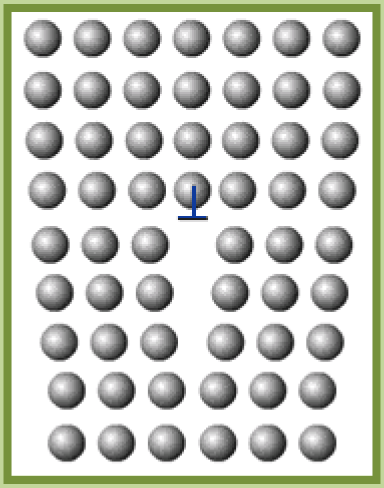
A precise "V" notch is placed in the bar. This can be ground or broached. The Charpy specimen is placed in a fixture such that the ends are held against a stop. A weight on a pendulum is raised. For example a 50 pound weight can be raised 3 feet (height h1 in sketch.) The weight is released and assuming very low friction bearings it will rise to a height h2. If for example that height is 1 foot then the energy absorbed was 50 lbs x 3 feet – 50 lbs x 1 foot or 100 ft-lbs. A simple pointer is used that records the maximum height achieved and is usually calibrated on a scale reading ft-lbs.

Other toughness tests are used but the Charpy test is repeatable and reliable. An interesting method exists that utilizes the ductility of the outer edges of the specimen which we have discussed,

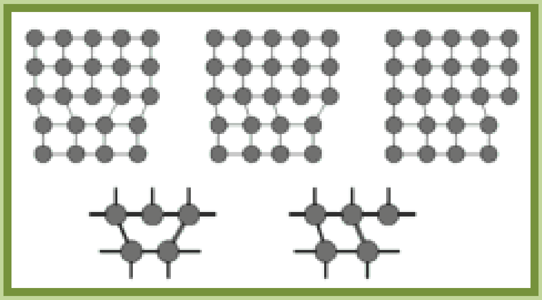
The deformation of the outer edges can be measured with a micrometer. Of interest the amount of deformation beyond the original 10 mm (0.394 inches) when measured in thousands (Mils) is often about equal to the energy absorbed in ft-lbs! Some specifications ask to have this Mils Lateral Expansion and well as the % Shear, as observed in the broken face, recorded.

Mechanism of Crack Propagation and Effect of Temperature

In metals, the atoms arrange themselves in a uniform crystalline type structure. These often form very rapidly and nucleate in multiple locations. When these crystals meet, they are in different planes and "defects" are created in this ordered arrangement. These "defects" are called "dislocations." They are line defects in a material's crystal structure. These gaps or separations create much weaker bonds than the bonds between the constituents of the regular crystal lattice. These bonds are the first to break during plastic deformation. Dislocations are actually gaps or voids in that they do not exist. They are vacancies in the host medium.



Dislocations are usually arranged in what are called edge and screw type and a combination of these structures. Sufficient to say for this discussion; as the material is strained the crystal structure on one side of the dislocation may form a strong bond with those atoms on the other side of the void.

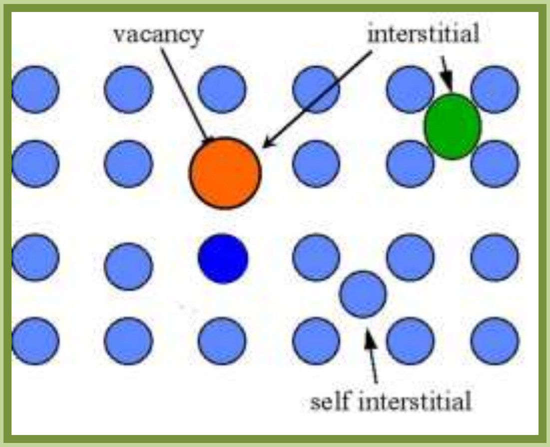


The gap may in essence move (see above skematic.) Therefore the dislocations are said to move under strain. Also more dislocations will form. These voids or gaps may contain impurities such as oxides, carbides, nitrides etc that form during the melting, solidification and solid state transformation processes. Some of these materials will inhibit this dislocation movement or "pin" the dislocation for that level of stress. In essence it will require more energy to "move" them when these interstitial elements are present.

The strained bonds around a dislocation can be viewed like electric fields. There are compressively strained bonds directly next to a dislocation and tensile strained bonds beyond the end of the dislocation. These form compressive strain fields and tensile strain fields, respectively. The visible results of plastic deformation are the result of dislocation motion. For example, the stretching a specimen in a tensile tester is accomplished through dislocation motion on the atomic scale.

All body-centered cubic metals, like iron, show a marked temperature dependence of the yield stress. This means that as the temperature is lowered the first dislocations to move will do so more rapidly. That is the reason crack propagation in a Charpy specimen will occur faster and require less energy at lower temperatures.

The interstitial atoms; carbon compounds, nitrogen compounds, etc will cause the steel to exhibit a sharp yield point either by the



catastrophic breakaway of dislocations from their interstitial atoms or by the rapid movement of newly formed dislocations. There is a transition temperature reached where the energy required for the crack to propagate is very low. Steel will often behave like "glass" once this lower temperature is reached and the material subjected to high stress.

Have a MIG (Wire) Welder?

A Friend with a MIG Welder? Know Someone with a Fabrication Shop?

Do Them a Big Favor and Have Them Review the Shielding Gas Saving Information on Our Web Site:

www.NetWelding.com

If You Have a Home Shop - Have You Run Out of Shielding Gas on a Saturday or Sunday? We Have a Solution:

How Much Gas Can Be Saved??

The best way to show the savings is with an example from one of our industrial customers who tested the system then bought them for all 35 of his MIG welders.

A Texas Truck Box manufacturer evaluated the system on a repetitive job, welding doors. With their standard gas delivery hose they welded ***236 doors*** with a full cylinder of shielding gas. Just substituting their gas hose with our patented ***GSS*** maintaining the same flow settings they welded ***632 doors***! That's a 63% reduction in shielding gas use.

Weld Performance Improvement

A small shop owner provided this

feedback after he purchased a 3 foot ***GSS*** for his small MIG welder. Al Hackethal reported these findings:

"Well, I can't believe it. I never thought a hose could make that much of a difference. I had a small job that's been waiting for a while. The weld quality, and even penetration is considerable better. Almost no spatter! The weld seemed to be hotter and I turned my MIG down a notch.

Initially thought that my imagination had kicked in, but then realized that the gas I'm buying is actually working the way it's supposed to. Glad I found your website. This is one of the few things that really works better than any info could suggest. I understood the theory, though in practice I understood much better after the first couple of welds. Now I have better looking welds and almost no spatter, which means less grinding and finish work! In addition, the tip was cleaner after the job I just did.

This will provide savings in time, labor and maybe even consumables too. As a one man shop there's never enough time for anything.

Al also has a TIG welder with 300 amp water cooled torch and bought one of our Leather Cable Covers. His email said this about it!

Oh, the leather wrap for my TIG hoses worked very well and fits perfectly. I'd just replaced the hoses and was looking for something to protect them that was better than the nylon wrap that's available around here. Now I'm "TIGing" again too, and much safer. It's good to know the coolant hoses are well protected. Much better than using a 300 amp TIG and then realizing that I was standing in a puddle of coolant, which is what recently happened. Can't pay the bills if I electrocute myself!

Thanks for making products affordable".

Another Home Shop Writes About GSS System

Perry Thomasson has a very well equipped home shop. He uses a 175 amp MIG welder. However the small welder cart only held a medium size shielding gas cylinder and Perry wanted to reduce the number of times he had to have it filled.

He purchased the largest cylinder his distributor offered for sale and chained it to a wall in his shop. He needed a much longer gas delivery hose so he added a 50 foot conventional 1/4 inch ID hose. He found he was using a lot of gas.

He purchased a 50 foot long ***GSS*** and saved a significant amount of shielding gas while improving his weld starts by reducing the starting gas surge. Since his regulator/flowgauge had a hose barb on the output, we supplied Perry with a splice connection on the supply end of the ***GSS***. He simply cut the existing gas delivery hose close to the regulator and spliced in the ***GSS*** hose. The welder end uses a standard CGA fitting that is supplied with the system.

Perry emailed a picture and said;

" The system works great. Thanks for the professional service and a great product."

A Professional Street Rod Builder Had This to Say About the GSS*:*

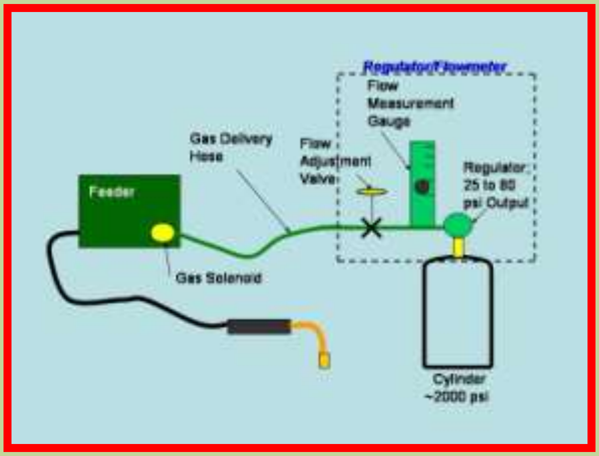
They use a 250 amp MIG welder with built in feeder and a 6 foot gas delivery hose. With their standard gas delivery hose the peak shielding flow at weld start was measured at 150 CFH, far more than needed and enough to pull air into the shielding stream. Air is then sucked into the gas stream causing poor weld starts and possibly weld porosity.

With the ***GSS*** replacing their existing hose, the peak flow surge at the weld start was about 50 CFH and it quickly reduced to the 25 CFH setting. With the many short welds made and frequent inching of the wire, they used less than half the gas and had better starts.

Kyle Bond, President, indicated a big benefit is the reduced time and effort changing cylinders since it's required less frequently. He quickly saw the improvement achieved in weld start quality as a significant advantage! Kyle, an excellent automotive painter, was well aware of the effects of gas surge caused by pressure buildup in the delivery hose when stopped. He has to deal with the visible effects in the air hose lines on the spray gun in his paint booth! It's too bad we can't see the shielding gas waste as Kyle can the effects of excess pressure when he triggers his spray gun! The paint surge is visible and creates defects unless the gun is triggered off the part being painted! Kyle can manage the surge by triggering the paint gun off the part; unfortunately we can't start our weld with the MIG gun off the part ! The ***GSS*** has a built in surge flow limiting orifice that keeps the peak flow from becoming excessive. So you not only save gas you improve your weld starts!

How Does The GSS Work?

Gas waste occurs every time you pull the MIG torch trigger even if it's only to inch the wire to cut off the end.



To keep flow at the preset level the gas pressure in the cylinder regulator will be between 25 and 80 psi. Flowgauge regulators (those with a flow calibrated pressure gauge) operate in this pressure range as well.) However to flow shielding gas though the welder and torch typically requires 3 to 5 psi depending on restrictions. Therefore every time welding stops the pressure in the gas hose raises to the regulator pressure of 25 to 80 psi. That stores up to 7 times the hose volume of gas in the hose. This is similar to your shielding gas cylinder which holds about 150 times the volume of gas as the physical volume of the cylinder due to the high pressure!

The patented ***GSS*** stores over 80% less gas then typical shielding gas hoses. In addition to the wasted gas (which you can hear when you pull the torch trigger) the high flow also causes air to be pulled into the turbulent shielding gas stream! This is like starting with the gas cylinder shut off! You have probably experienced that before when you forgot to open the valve!

It takes a short time for the shielding gas flow to return to a smooth less turbulent (laminar) flow even when the start gas surge flow reduces. That can take several seconds so when making short welds or tack welds you're not getting all the benefits of the shielding gas you're purchasing!

SUMMARY:

The ***GSS*** can cut your gas use in half or more. It also has a surge restriction orifice built into the fitting at the welder- wire feeder end. That limits peak flow (*but not your set flow*) to a level that avoids excess turbulence for better starts. It allows a controlled amount of shielding gas to quickly purge the weld start area.

All you need to do is replace the exiting gas hose from cylinder regulator to welder with our patented *GSS*. *It is available in various lengths at* www.NetWelding.com .

There are more testimonials at:

http://www.netwelding.com/production_test_results.htm

Have more questions? See:

http://www.netwelding.com/Overview_GSS.htm

Or email us at:
TechSupport@NetWelding.com