

## **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 that 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. However, 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 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 over 40 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 10 patents in the welding field, with 4 of 5 recent ones related to reducing shielding gas waste and improving weld quality. A patent issued in 2012 is of a unique enclosed design welding helmet that not only filters breathing air but also cools it employing a solid-state, thermoelectric cooling module. He has published a number of articles related to welding in technical journals and a book entitled "Advanced Automotive Welding."*

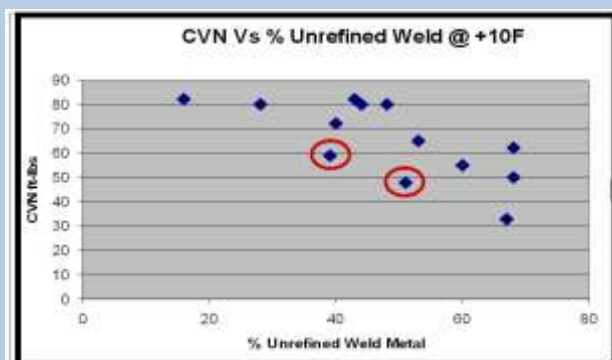
Background

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

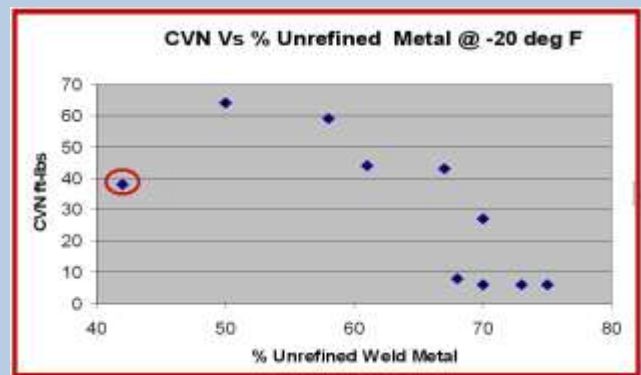
Plotting CVN toughness at +10 degrees F provided the following graph:



As noted there is reasonable correlation with the toughness and percent

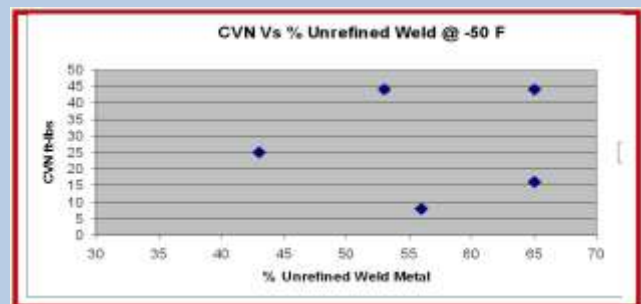
unrefined weld metal. Therefore the reheated area (HAZ) of the previous weld bead has a more refined metallurgical structure and higher toughness. There are two anomalies that are circled in red. These points do not provide a good correlation. Tests that will be described subsequently discuss these circled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

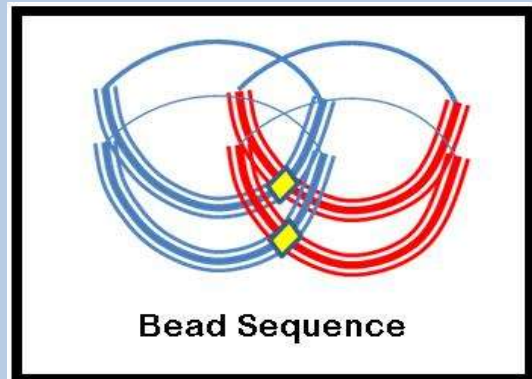
This deformation absorbs a great deal of energy. However even if the center is the exact same material it may have a brittle appearing center because of high triaxial stresses. The picture left illustrates these two zones in this broken Charpy. This was a uniform plate material yet the center fractured 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.

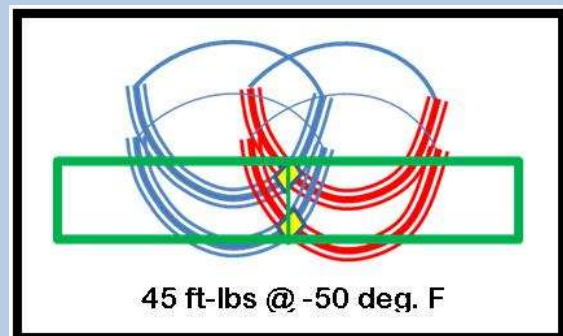
Therefore he asked that we make a large weldment so: 1) there would be no influence of base metal dilution and 2) he could place the Charpy specimens exactly where he wanted. We made a six layer wide by six layer deep weld using a heavy backing bar simulating a thick vessel weld which is what this research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

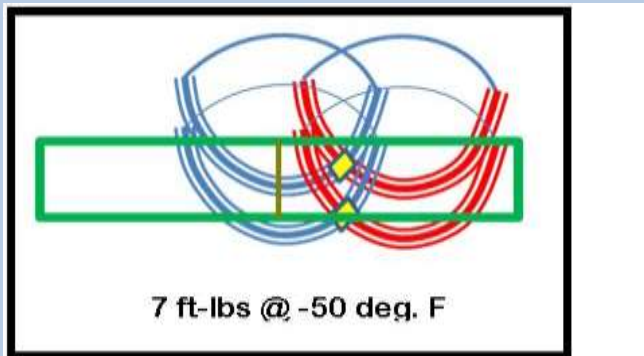


This is a representative view of what Dr. Nelson was able to see and then place each Charpy in the desired structure.



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

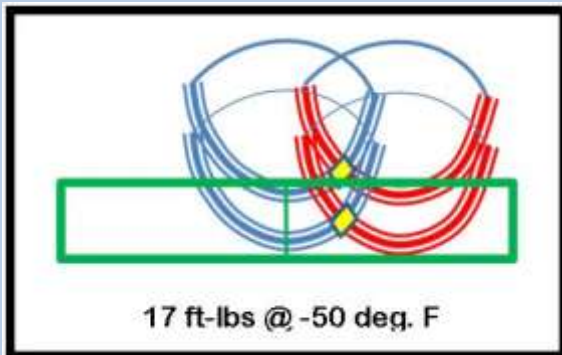
matched the 44 ft-lbs found in the previous examinations.



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!

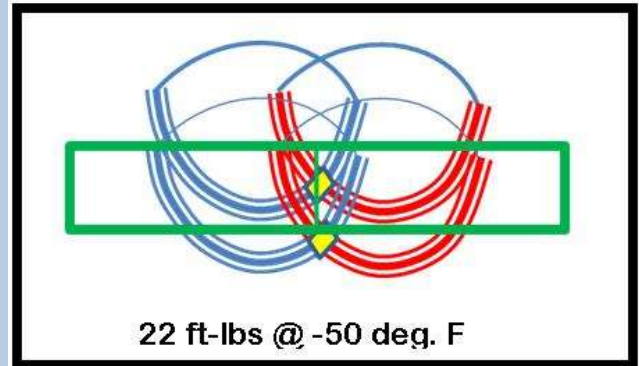
Dr. Nelson made a series of 3/4 size Charpys from the weld in attempt to have only the top bead in the broken area. However it was difficult to get exact placements and he concluded the toughness was not much different than the lowest value achieved even with single refined material in the center.

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 than 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**

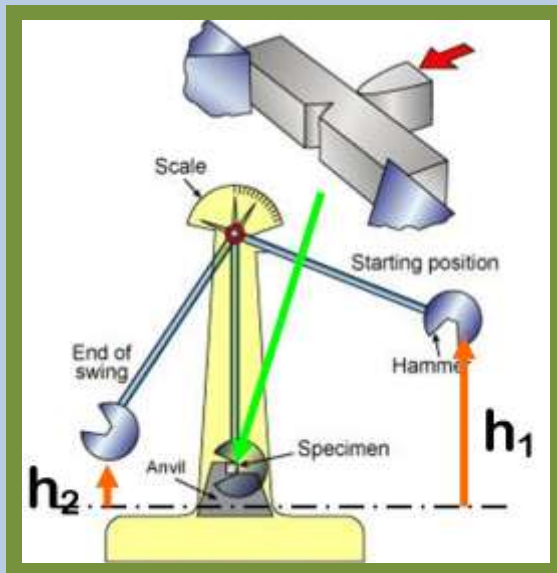
The Appendix provides more information about Charpy testing in general and a brief overview of why steel becomes brittle at lower temperatures.

## 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  $\frac{3}{4}$ , and  $\frac{1}{2}$  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  $h_1$  in sketch.) The weight is released and assuming very low friction bearings it will rise to

a height  $h_2$ . 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.

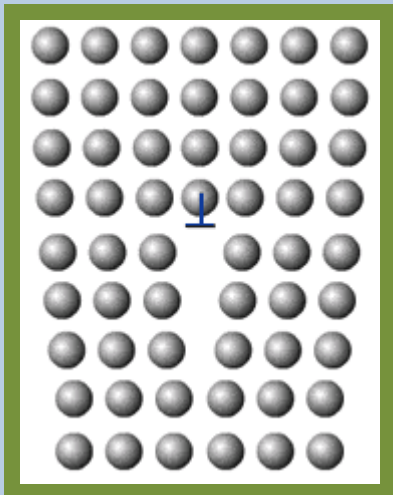
Other toughness tests are used but the Charpy test is repeatable and reliable. An interesting method exists that utilizes the ductility of the outer edges of the specimen which we have discussed,



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.

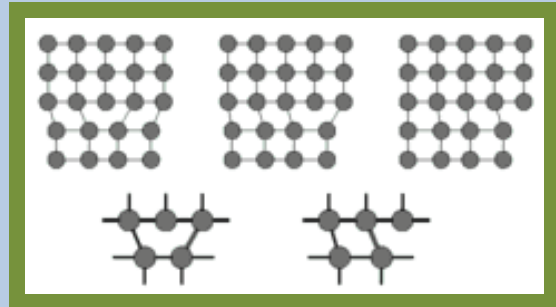
### Mechanism of Crack Propagation and Effect of Temperature

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.

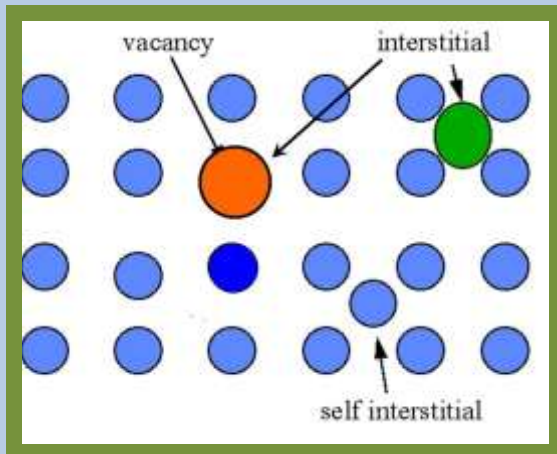
The strained bonds around a dislocation can be viewed like electric fields. There are compressively strained bonds directly next to a dislocation and tensile strained bonds beyond the end of the dislocation. These form compressive strain fields and tensile strain fields,

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.

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.

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

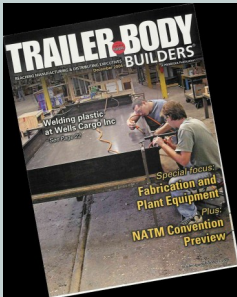
# WATechnology

## Gas Saver System Saves Millions for MIG Welders!

With thousands of Gas Saver Systems (**GSS™**) in use our customers collectively save millions of dollars annually by reducing shielding gas waste.

### THE PROBLEM

Several independent published articles quantify the enormous waste in shielding gas experience by most users of MIG welding. An article published in Trailer Body Builders Magazine (Reference 1) quotes a representative from a leading manufacturer of shielding gases, Praxair, indicating the average fabricator using MIG welding consumes 30 cubic feet of gas per pound of wire consumed. That is 5 to 6 times what should be used or a simply calculation of arc time multiplied by gas flow rate defines as needed.



### WHAT CAUSES THIS WASTE

Several factors create the waste but we have quantified a major cause—gas surge at the weld start! High pressure in the gas delivery hose when welding stops causes this gas surge at the weld start. Details are outlined in an article published in the American Welding Societies Journal. See Reference 2.

### AMOUNT OF WASTE CAUSED BY GAS SURGE QUALIFIED: A Truck Box Manufacturer Saves 63% Shielding Gas Simply by Installing Our Gas Saver System.



Tests were conducted using cylinder gas. With their standard gas delivery hose they welded **236** doors with one cylinder. They installed our Gas Saver System and with no other changes welded **632** doors with one cylinder! *They instantly ordered 25 for all the MIG welders they had at the time.*

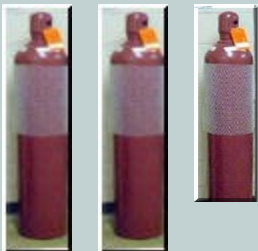
Stated another way; to weld 632 doors with their old system they would have used **2.7** cylinders versus **1** with the **GSS!**

After several years of use they added new MIG welders. **They called and asked for 10 of the "Magic Hose" - stating the product works great !!**



**Number of Cylinders Needed  
With Standard Gas Delivery Hose**

**Number of Cylinders Needed  
With Gas Saver System!**



## EVEN A 6 FOOT GAS DELIVERY HOSE CAN SAVE 25 to 40+% SHIELDING GAS

The amount of shielding gas waste and therefore the savings potential depends on a number of factors. The length of shielding gas delivery hose determines the amount of excess gas stored when welding stops. The number of starts and stops are a key factor. The pressure in the gas delivery system is also important. However a minimum of 25 psi is needed to maintain the Automatic Flow Compensation built into gas delivery systems since the introduction on MIG welding. Significantly higher than needed for gas flow. For pipeline gas supply 50 psi is often used producing a high gas waste.



## MANUFACTURER WITH ONLY 6 FOOT LONG HOSES SAVES UP TO 40+%

A manufacturer of automotive exhausts employs 128 Robot Welders in one plant. They have only 6 foot shielding gas hose from the flow control at the gas source to the gas control solenoid. After a large number of tests of the **GSS** conducted during a Black Belt Lean Manufacturing Study the welding engineer measured from 25 to 40+% shielding gas savings depending on the specific weldment. After the results were in they quickly installed **GSS's** on all 128 of their Robotic Welders!

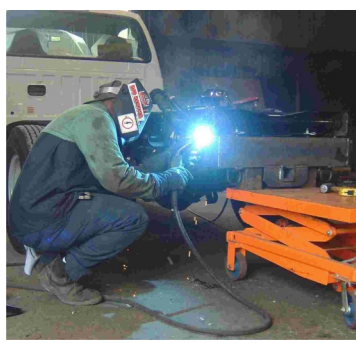
In addition, the controlled amount of shielding gas delivered at the weld start, at a flow rate that does not pull air into the gas stream, can eliminate the need for preflow. Preflow is sometimes used in an attempt to circumvent initial high gas surge causing air aspiration and resulting inferior weld starts. This is particularly a problem with Pulsed MIG welding. With the **GSS** optimum starts are achieved without wasting valuable cycle time and shielding gas.

Since the **GSS** retains gas delivery pressure, Automatic Flow Compensation is maintained. This is critical in Robotic Welding operations where high duty cycles can clog welding torch gas passages with spatter and debris from the welding wire. A reduction in flow occurs if this feature is not maintained (*as occurs with low pressure systems.*) (Email for details of how this built in feature operates.)

## TRUCK BODY BUILDER SAVES 50% OF SHIELDING GAS USE

Double AA Body Builders in Pamplico South Carolina tested a **GSS** and found he could weld twice as much with one gas cylinder!

MIG welding is employed using 0.035 inch diameter solid wire and Argon/CO<sub>2</sub> shielding gas. This allows welds to be made in all positions with minimum spatter to reduce post weld grinding. Shielding gas is piped throughout the shop with most of wire feeders located 30 feet from the gas supply pipeline. Some welders in the shop center use cylinder gas supply. Ken Ard, President, knew they were using more shielding gas than needed. Ken heard about the benefits of a recently invented product to reduce gas waste. He arranged a test



on two welding machines with shielding gas supplied with cylinders. The test started with full gas cylinders on both welders. One welder incorporated the **GSS** and the other used their standard ¼ inch diameter shielding gas delivery hose. Ken had read about the benefits of the **GSS** system and was pleased but not surprised that he achieved about twice the amount of welds with the cylinder of gas on the system with the **GSS** installed. Both MIG welders operated at the same welding current and used about the same amount of wire during the test, validating that they were working for about the same amount of time. Ken installed **GSS's** on all 23 MIG welders. Payback was measured in weeks! They have added 20 more welding machines since the initial tests. All 20 use the **GSS**. Since the **GSS** cost is not

much higher than a conventional gas hose, payback is a non issue, "*Just Do It*", states Ken! Details were published in Trailer Body Builders magazine (Reference 3.)

## TEXAS HYDRULICS SAVES 35% WITH FLOW RATE LIMITERS



Texas Hydraulics utilizes MIG welding to fabricate hydraulic cylinders with bores ranging from 1 inch to 15 inches; with some 20 feet long. Doug Watkins, Welding Engineer for their Texas plants, found their welders were able to adjust flowmeters at any time at a shielding gas flow beyond the range of their Welding Procedure Specification (WPS). Some were found with the flow measurement ball pinned to the top of the flow tube. Mr. Watkins indicates, "We have found with our flowmeters that can mean a flow rate of 100 CFH or higher is being used. In addition to the gas waste, any

flow setting beyond about 50 CFH with our electrode extension pulls air into a turbulent gas shield. That air creates weld spatter and possibly internal (or even external) weld porosity."

By installing 30 WA Technology Flow Rate Limiters (WAT-FRLL) and limiting the maximum flow that can be set, they assured a quality shielding gas stream and eliminated gas waste. The maximum flow rate is now set at 40 CFH and this setting locked-in. After an initial gas use audit, the calculated shielding gas savings was measured at 25%. With follow up audits the actual savings exceeds 35%.

Texas Hydraulics also has begun changing its shielding gas delivery hoses to **GSS**'s. During their initial testing they showed an 18% reduction in shielding gas use with less initial gas surge.

According to Mr. Watkins, "By using the Flow Rate Limiters we are building a quality product and controlling our consumable cost which continues to be more valuable every day. By switching to the new **GSS**'s we expect to show greater than 20% additional savings due to the frequent starts and stops. Doug sent us this email; *"I really appreciate your companies' assistance; it helps me do better at my job. WA Technologies has contributed directly to helping us control our cost in welding consumables and help us remain competitive in our effort to provide the best product for the right price."* See Reference 6 for published details.

### DETAILS OF FLOW RATE LIMITER

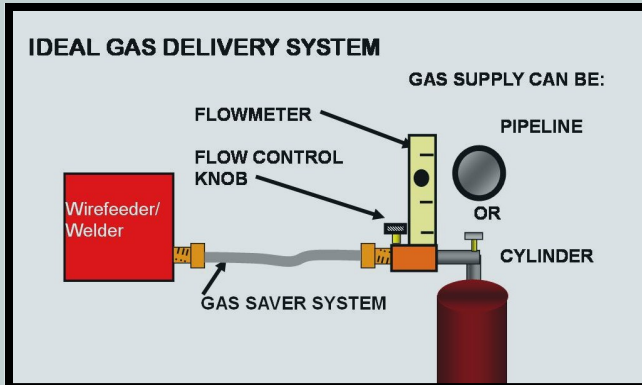
Welders often believe the adage; *"If Some is Good More Must be Better,"* when it comes to setting shielding gas flow rates! Two published articles indicate that beyond about 50 CFH Turbulence flow is created in the shielding gas stream. It is counter productive to increase gas flows above this level since moisture laden air is pulled into the gas stream. One article by The Welding Institute in the UK defines the transition to Turbulent flow occurring at about 50 CFH with a common 5/8 inch torch nozzle (Reference 4.) Kevin Lyttle, Manager Welding R&D for Praxair, published an article in a 2005 (Reference 5) indicating 35 to 45 CFH gas flow is what be used in MIG welding. The article further states, *"In many instances production site surveys indicated that typical shielding gas flow rates exceed 50 CFH. This can contribute to poor weld quality as atmospheric gases are draw into the weld zone because of excessive weld turbulence. Optimum flow enhances weld quality and reduces shielding gas usage."*



Our simple **Flow Rate Limiter (WAT-FRLL)** fits most regulator flowmeters and flowmeters used on pipelines. On some model flowmeters with the control set to maximum we have measured flow rates of 150 CFH! With our WAT-FRLL the maximum desirable flow rate is set, the WAT-FRLL is placed over the flow control knob and a set screw locks it in place. A pad lock and pin are installed blocking access to the set screw. The flow can be lowered some amount depending on the flowmeter model but can not be increased! It's simple to stay within your Welding Procedure Specifications! Details available on our web site.

## IDEAL GAS DELIVERY SYSTEM

We are often asked what we recommend for a gas delivery system. For systems with up to



50 feet (possibly longer, email) from the gas supply to wire feeder (or wherever the gas control solenoid is located) one of the best systems is shown in the schematic left. It consists of a rotameter flowmeter (one with a flow indicator ball) and our **GSS**. This system will work for both cylinder or pipeline gas supply.

The benefits are: 1) gas flow is quickly read by the position of the flow indicator ball; 2) the **GSS** reduces the normal gas waste associated with these systems by 80+%, and controls gas surge velocity

within limits that minimize start turbulence improving start weld quality; 3) a controlled amount of extra shielding is quickly delivered at the weld start to purge air from the start area, torch nozzle and torch gas hose, producing higher quality weld starts with less spatter and internal weld porosity.

The **GSS** also maintains the system pressure so Automatic Flow Compensation is maintained. This feature maintains flow even when spatter builds in the torch nozzle or torch cables are twisted etc. Other flow control options such as the use of fixed orifice flow controls are a compromise. Welders often believe they need more gas and drill them out! Flow controls of any type placed at the feeder do not provide sufficient extra gas at the weld start to purge the weld start area and nozzle of moisture laden air. This often causes welders to set higher steady state flow rates in attempt to compensate (which they can not fully achieve.)

## References

1. Weber, R., How to Save 20% on Welding Costs. Trailer/Body Builders, Volume 44, Number 3, January 2003
2. Uttrachi, GMAW Shielding Gas Flow Control Systems; The Welding Journal, Vol. 86, No. 4, April 2007
3. Uttrachi, G, A Solution to Weld Shielding Gas Waste. Trailer/Body Builders, Volume 45, Number 14, December 2004.
4. FWilkinson, M. E., Direct Gas Shield Analysis to Determine Shielding Efficiency. Report of The Welding Institute, Cambridge, England, December 1974
5. Lyttle, K, Stapon, G Simplifying Shielding Gas selection, Practical Welder, February 2005
6. Texas Fabricator Reduces MIG Welding Shielding Gas Waste, Trailer/Body Builders, Vol. 47, No. 12, December 2006

## MORE INFORMATION AVAILABLE ON OUR WEB SITE

There is a great deal more information on the subject of gas flow management available on our web site. Over 10 production examples with savings data are presented. The theory as to how our patented system works is covered. Products are also available to lock flow controls to the maximum flow rate desired while still providing welders with some flow control.

You can also Email us at [TechSupport@NetWelding.com](mailto:TechSupport@NetWelding.com)

See

[www.NetWelding.com](http://www.NetWelding.com)  
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Other products covered by US Patents 7,015,412 and 7,019,248