



## Welding Math (and some physics)

By Jerry Utrachi

Understanding what causes a MIG wire to melt and what controls weld penetration is very helpful in producing quality weld deposits and solving welding problems.

The relationship of gas pressure and volume is helpful in setting shielding gas flow and eliminating gas waste. Bernoulli developed these gas equations in the 17 hundreds and Torricelli in the 1630's understood the basic properties of gases. The flow rates that cause turbulence in a MIG shielding gas stream must be known and avoided for quality MIG shielding. Reynolds in the late 18 hundreds defined the flow rate that produces turbulence. John Dalton in the early 18 hundreds defined that the pressure of gas mixtures is an addition of the pressure of the individual gases. The implication for welding is if shielding gas leaks from a hose or fitting, air and moisture are "flowing back through that same hole!"

When asked to make a 3/16 versus a 1/4 inch fillet weld fractions must be understood. Or if told the fillet weld specification indicates a 5 mm size is needed, a conversion to properly rounded US units is necessary.

The information in the report is useful to welding students, welders wishing to advance to welding technicians, welding robot operators, welding supervisors, etc. It presents some welding math and physics and discusses how to use the information. Most of these topics are on our web site or in PDF Downloads available on our web site - in most cases, more detail is presented. Where this additional information is available, a web site link is provided so it may be readily accessed. We also offer an 87 page Self-Study, Learning Program on Welding Math and Science that employs a step-by-step approach. See link below.

### About the Author

*Jerry Utrachi is President of WA Technology, a company he founded in 1999 dedicated to helping companies improve welding productivity and specializing in products and techniques to eliminate shielding gas waste.*

*Mr. Utrachi started his career in the welding field over 45 year ago in welding R&D at the Linde, a leading company developing welding shielding gases, equipment and filler metals. 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, L-TEC. He was responsible for Business/Product Management, Marketing, Customer/Technical Service, Special Customer Order Production, Training 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.*

*Mr. Utrachi was on The American Welding Society Board as Director at Large, three years as Vice President and the 2007 President of the 70,000 member Society. He was Chairman of the Board of Trustees for the Societies Education Foundation for 6 years until December 2014. He is also a member of ASME and Chairman of his local Section.*

*Mr. Utrachi has a Bachelors and Masters degree in Mechanical Engineering and a Masters in Engineering Management from the New Jersey Institute of Technology. He has 11 patents in the welding field, with 4 of 6 granted in the past 10 years related to reducing shielding gas waste and improving weld quality. Two patents granted in 2012 are for unique designs of welding helmets that not only filter breathing air but also cool the welder by employing solid-state, thermoelectric cooling modules. (Note: these two helmet patents are available for license. Email [Jerry\\_Utrachi@NetWelding.com](mailto:Jerry_Utrachi@NetWelding.com) if interested.)*

*Mr. Utrachi has published a number of welding related articles in technical journals. In 2012, a 176 page book he authored, entitled "**Advanced Automotive Welding**," was published by CarTech, Inc as part of their Pro Series, see: [BOOK DETAILS](#)*



**Also Available, an 87 page, "Welding Math and Science" Self-Study, Learning Program See: [PROGRAM DETAILS](#)**

Topics covered:

Topic	Page	What is Covered
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C	3	Effect of Welding Current on Weld Penetration
D	5	Effect of Gas Pressure on Gas Volume
E	6	How to Read a Ruler (with information on working with fractions and common metric conversions)
F	12	Calculate Shielding Gas Waste; (dealing with percentage)
G	15	Reynolds Laminar versus Turbulent Flow
H	16	Dalton Partial Pressure (gas leaking out of a shielding gas hose means moisture laden air is flowing back in!)
I	17	Calculate Weld Volume
J	20	Calculate Weld Cooling Rate

### Topic A: Why Do We Need Math?

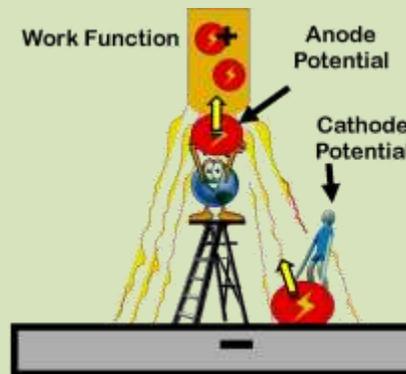
To become a highly skilled welder it is desirable to understand some welding math and basic welding physics. It is presented here in a way that doesn't make it painful!

**It Could Be Tougher:** Imagine trying to do math in Roman Numerals! Actually, addition is not a big problem you just put all the letters together and rationalize extra letters denoting numbers; for example if you have three V (5's) they would be restated as XV for 10 and 5. However division is much more difficult and a Roman "Calculator" called a "Counting Board" is needed. Pebbles are placed in numbered boxes etc. As for fractions, the Romans didn't have a way to write them as numbers. They would state fractions in words, for example as in the case of a ruler defining 3/16; "three of 16 parts." In fact, maybe they made understanding fractions easier - they just said what they represented; "divide a unit in 16 parts and count only 3 of them!" You can Google Roman Numeral math if interested.

### Topic B: What Causes MIG Welding Wire to Melt?

**Hint:** this is what it is NOT; a) the "hot arc", b) radiation from the arc or c) the wire passing through the arc. Two phenomena are primarily responsible for wire melting:

1. *The first reason is wire stickout.* As the wire passes from the end of the MIG gun contact tip to the arc, it is carrying all the welding current and becomes very hot. It starts at room temperature and can exceed 500 degrees F before the arc forms at the end (depending on the "stickout," the distance between the tip and the work piece.)
2. *The second reason it melts is that current leaving or entering a surface, be it wire or hot puddle, requires a given amount of energy for the electrons to enter or leave that surface.* This energy, generated at the surface, melts the already hot wire. Therefore assuming Electrode Positive this is referred to as Anode Potential (also called Work Function and measures as voltage) and is equal to the Amps x Anode Voltage.



The following equation obtained from Reference (1) page 3, defines the relationship:

$$\text{Wire Melting Rate (lbs/hr)} = a * \text{Amps} + b * \text{Wire Stickout} * \text{Amps}^2$$

Where "a" and "b" are constants and "Wire Stickout" is the distance from the MIG gun contact tip to the work piece measured in inches. (Note, constant b has been modified to compensate for the fact that this equation was based on "Electrode Extension" that is measured to the top of the arc.)

The values for "a" and "b" for 0.035 inch diameter carbon steel wire are:

$$a = 0.017; b = 0.00014$$

These two energy sources cause the wire to melt. The first term (a \* Amps) is the anode voltage times current and the second term defines the energy input due to resistance heating.

**Topic C: EFFECT OF CURRENT ON PENETRATION**

A major implication of the wire melting relationship is with increased stickout (at a fixed wire feed speed) amperage will decrease. That has a significant effect on another parameter, weld penetration.

Weld penetration can be determined by a simple equation defined some years ago by C. E. Jackson in Reference (2)

Weld Penetration (distance into the base material when making a weld on plate measured in inches) =

$$K [Amps^4 / (Weld Travel Speed; ipm * Volts^2)]^{0.333}$$

For 0.035 inch diameter solid carbon steel wire, the constant K = 0.0019

Using these equations we find the following when we change wire stickout for 0.035 inch solid wire. Assuming a fixed wire feed speed that produces 200 amps at 3/8 inch wire stickout:

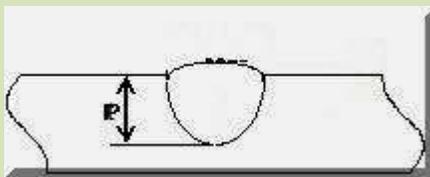
Stickout, inches	Amps	Penetration inches	% Loss in Penetration
3/8	200	.127	base
1/2	184	.114	11%
5/8	172	.104	18%
3/4	162	.096	24%
7/8	154	.090	29%

Note:

1. With a fixed wire feed speed the amperage decreased from 200 amps with a 3/8 inch stickout to a low of 154 amps when the stickout was increased to 7/8 inches. The resistance heating of the wire (the 2nd Amp<sup>2</sup> term in the equation) is a very efficient heating process. Therefore the current needed to finish melting the wire as it enters the arc, becomes less as the wire is hotter with longer stickout.
2. However there is a reduction in weld penetration when varying stickout in a normal range from 3/8 to 3/4 inches is 24%! If extended to 7/8 inches penetration decreases 29%.

Therefore it is very important to keep the MIG gun stickout constant. Also the shorter the distance from tip to work for a fixed wire feed speed the greater the penetration since current also increases. When welding in the short circuiting mode it is often desirable to use a long contact tip which protrudes from the shielding gas cup. This helps assure adequate penetration is maintained by keeping current higher. It also helps visibility so the welder can stay on the leading edge of the weld puddle.

**Weld Penetration Definition**



For the purposes of this exercise, weld penetration is a measure of how deep the weld penetrates in a bead-on-plate deposit. Have a different wire than the 0.035 inch solid wire used in this example? No problem. In fact not only changes in wire type and size but also shielding gas and MIG gun angle will alter the actual value. You can generate your own constant K for what you are doing by making a bead-on-plate deposit, cutting a cross section and etching it.

References:

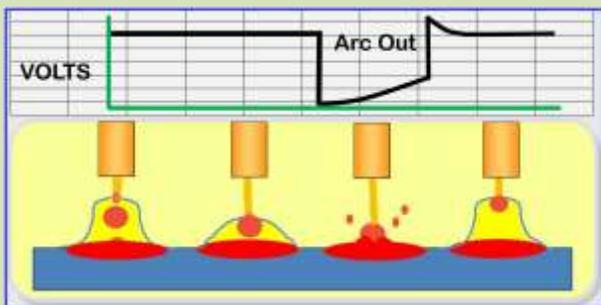
1. AWS Welding Handbook, Volume 1, 9<sup>th</sup> Addition; pp 7
2. "The Science of Arc Welding" by C. E. Jackson. 1960 Welding Journal 39(4) pp 129-s thru 230-s

The effect of welding parameter control, particularly wire "stickout," from a MIG gun contact tip to the workpiece and the resulting welding current change is very important to understand. The welding operator controls the amount of "stickout" when semi-automatic welding and when moving the MIG gun by hand. There are often locations where joint access does not allow the MIG gun nozzle room to maintain a desired "stickout." It must be understood that when "stickout" increases even though the resulting weld bead may

look good on the surface, the weld current reduced and the weld may have lack of penetration into the base material. This is very important when operating in the “short circuiting” or Short Arc” mode. This mode of metal transfer is commonly used when MIG welding out of position or when welding thinner materials. When welding in this mode it is common to use MIG gun nozzles and contact tip sizes that allow the tip to extend slightly beyond the nozzle opening.

### What is Short Art Welding?

If welding with 0.035 inch diameter wire below 165 amps, or with 0.030 diameter wire at below 150 amps the arc looks steady but is actually off for a percentage of the time. The welding wire is stubbing into the puddle many times per second to reduce weld heat. It is a controlled stubbing with short circuit current limited by the power source inductance and slope. The power supply design is a reason some welding machines perform better compared to others, especially in the “Short Arc” mode of metal transfer.



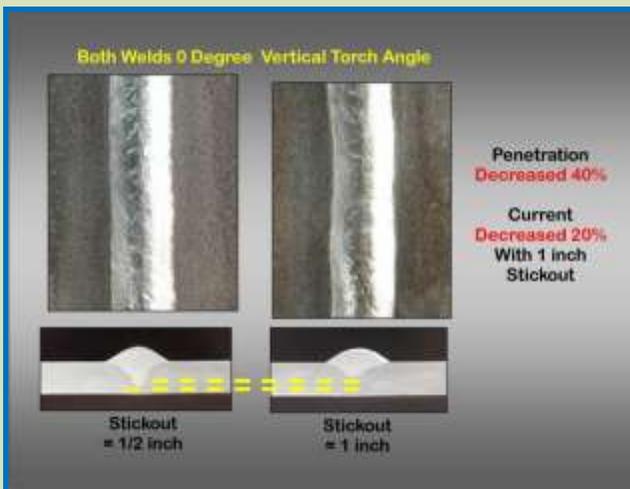
The picture left presents schematically what is occurring while “Short Arc” welding. It is one of 450 pictures in our recently published book, “**Advanced Automotive Welding**” that covers the three modes of MIG welding, Spray Arc, Short Arc and Pulsed Arc. It discusses in detail all welding (and cutting) processes; Oxyacetylene, TIG, Stick and MIG welding. It also presents information on Oxyfuel cutting, Plasma cutting, and an overview of Laser and Water Jet cutting

processes. It includes an overview of welding safety.

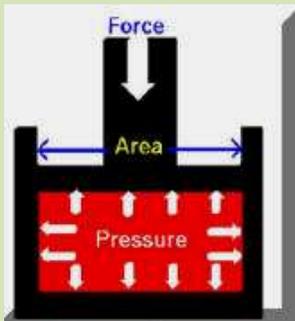
In addition to presenting, the math related to wire deposition rate or burn-off rate it has photomicrographs of the effects of changing welding “Stickout,” volts, and travel speed on weld penetration. The photomicrograph right is one shown in the book. It displays the effect of changing “stickout” on weld penetration. There are also photomicrographs of the effects of other variables on penetration presented, such as MIG gun angle relative to the workpiece.

The book is available for purchase at: <http://www.netwelding.com/prod02.htm#Book>

It is an excellent book for use by welding students, presenting formal welding process information, some welding science and metallurgy and many practical applications and project examples. The projects and applications relate to welding cars, street rods and racecars. It discusses the welding of carbon steel, chrome-moly steel, stainless steel and aluminum. It also presents an overview of welding titanium and magnesium. There are 450 colored pictures, which have detailed captions, making the book easy and enjoyable to read. It includes an extensive Glossary and is an excellent welding reference. It is also useful for welders with experience who want to understand the benefits of modern welding equipment and process variations such as Pulsed MIG welding. Examples are presented showing where Pulsed MIG welds can be made to look similar to TIG welds with excellent shape and without spatter. The welding an aluminum Corvette frame reviews why GM specifies the use of Pulsed MIG welding for this application.



**Topic D: Gas Pressure / Volume Calculations**



Understanding the relationship between gas pressure and volume will help when setting gas flow and understanding MIG shielding gas use and waste.

In 1662 Robert Boyle defined the basic relationship between Gas Pressure and Volume. He stated the relationship in mathematic terms as:

**$P_1 / P_2 = V_1 / V_2$**  (Where P, pressure, is measured as absolute pressure = gauge pressure + 14.7 psi at sea level)

For example, in a MIG gas delivery hose if the initial absolute pressure is doubled the gas volume must be double. That was until 140 years later when around 1800 both Charles and Dalton independently added temperature to the relationship!

They defined the following relationship:

**$V_1 / V_2 = T_1 / T_2$**  (Where T, Temperature is measured as absolute Temperature in degrees Rankin = Degrees Fahrenheit gauge + 460)

Applying this equation, we'll see in general we need not worry about temperature effecting volume in normal ranges:

i.e.  **$V_1 / V_2 = T_1 / T_2$**

If  **$T_1=75$  F** than  **$T_{Rankin} = 75+460=535$  R**

Assume  **$T_2 = T_1 + 20\% =90$  deg F**; then  **$T_2 Rankin = 90+460=550$  R**

**$V_1/V_2$  due to 20 % Temp Difference =**

**$V_1 / V_2 = T_1 / T_2 = 535/550=0.97$**

Alternatively, at a constant pressure, an increase in Temperature of 20% measured in degrees Fahrenheit yields only 3% increase in volume. For most welding purposes and over the range of production temperatures there is not enough change in Volume with gas Temperature to consider it significant.

The general Gas Laws can be written as:

**$(P_1 * V_1) / T_1 = (P_2 * V_2) / T_2$**

**It can also be written as  $P * V = (nR) T$**

where the constants nR can defined based on the gas. We'll let you find details about the nR by searching the Internet since for our purposes ratio comparisons are all we need.

**MIG WELDING EXAMPLE**

Assume:

1. The pressure needed in the gas delivery hose from gas source to welder/feeder to flow 30 CFH is 3 psi.
2. A regulator/flowmeter is used that employs an 80-psi regulator.  
Therefore, when welding stops gas continues to flow through the needle valve flow control (or orifice flow control) until the pressure in the gas delivery hose equals 80 psi.

Then the volume of excess gas in the gas delivery hose compared to the volume when welding will be:

**$V_{stopped} / V_{welding} = P_{stopped} / P_{welding} =$**

**$(80 \text{ psi} + 15) / (3 \text{ psi} + 15) = 5.3$  times the physical hose volume**

Hose Expansion Causes More Excess Volume: Tests of a standard 1/4 inch diameter gas delivery hose showed it had a 13% increased volume due to the hose expanding with 80-psi pressure.

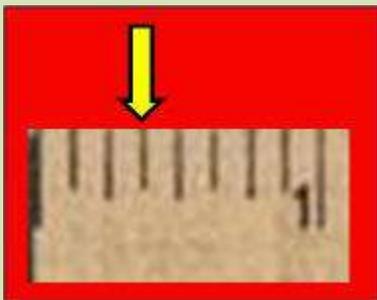
Therefore 87% of the excess gas stored in the hose is due to the increased Pressure and 13% of the excess due to Hose Expansion.

3. Excess Gas Blasts Out of the MIG Gun When Welding Starts: The high velocity creates turbulence in the shielding gas stream, which takes several seconds to stabilize to a desirable smooth Laminar flow. The turbulence pulls in air causing excess spatter and internal weld porosity. For a typical 5/8 inch diameter MIG nozzle more than 50 CFH flow **rate causes this** turbulent flow. For a smaller 1/2 inch diameter, nozzle flow rates should not exceed about 40 CFH.

**Topic E: How To Read A Ruler** (Includes Basics of Fractions and Common Metric Conversions)

Reading a ruler in *US Units* requires working with *Fractions*. If the Metric System was being used it would not be needed- but more on Metric below.

Rulers and measuring tapes are commonly calibrated in feet and inches. Instead of segmenting the foot into 10ths of a foot, it is divided into 12 parts labeled inches.



The inch is commonly split into 8, 16 or sometimes 32 parts. Therefore working with fractions is a necessity. A fraction of an inch is a mathematical way of showing the number of the parts into which it is divided. For example, 3/8 inches is a way of showing a measure of 3 of the 8 parts into which it was divided. The picture left is an example of an inch split into 8 parts or eighths. The yellow arrow is pointing to the third line

from the start or the 3rd of 8 parts stated as 3/8. It's shown with a division line because we could divide 3 by 8 and get 0.375 the decimal value. Now if the number of segments and the total number of segments into which the inch mark was split were always stated, fractions would be relatively easy-but it is not that easy!

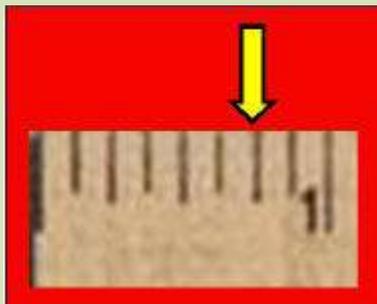
**SIDE BAR: Why is Time and US Measurement Broken Into 12's Instead of 10's?**

The Egyptians were responsible for the 24-hour day. The Egyptians were fond of counting in base twelve (instead of base 10, which is commonly used today). This is thought to be because they counted finger joints instead of fingers. Each of finger has three joints, so if you count by pointing to finger joints with your thumb you can count to twelve on each hand. This seems arbitrary, but is actually just a strange as counting in base ten simply because we have ten digits!

The example, the picture on the right shows the 4th of the 1/8 inch marks in red. Since 4 is 1/2 the way to 8, it is the 1/2 inch mark. We could have said 4/8 which is the same as saying 1/2 . It is usually desired to display the fraction by having the lowest whole number at the bottom.



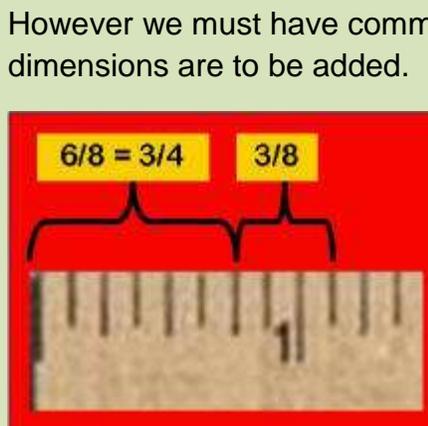
If the bottom number (called the denominator) can be divided by the number on top (called the numerator) and a whole number is the result - the fraction would have the lowest number possible in the denominator.



Looking at the picture left and counting from the start or zero mark there are 6 spaces or 6/8 of an inch. Dividing 8 by 6 produces 1.333 which is NOT a whole number (one with no decimal left over.) However both numbers can be made smaller. Any number or fraction can be multiplied or divided by 1 without changing its value. This can be accomplished by multiplying or dividing both the numerator and denominator by the same number. Both the numerator and denominator could

be multiplied by 2 (actually 2/2) that would give 6 \* 2= 12 for a numerator and 8 \* 2 or 16

for the denominator. The fraction would become 12/16. That would be accurate and a person could be told to go cut a steel rod 12/16 of an inch long. However the objective is to have the smallest numbers. Both numerator and denominator could be divided by 2. That would give 6/8 = 3/4 for a numerator and 8/2=4 for a denominator. The fraction now becomes 3/4. It is the same value as 6/8 but with smaller numbers. Notice on the ruler there are some lines longer than others. In this case the longest lines are quarters of an inch rather than eighths. Three of these longest lines could have been counted and it would be found more quickly as the third quarter or the 3/4 mark!



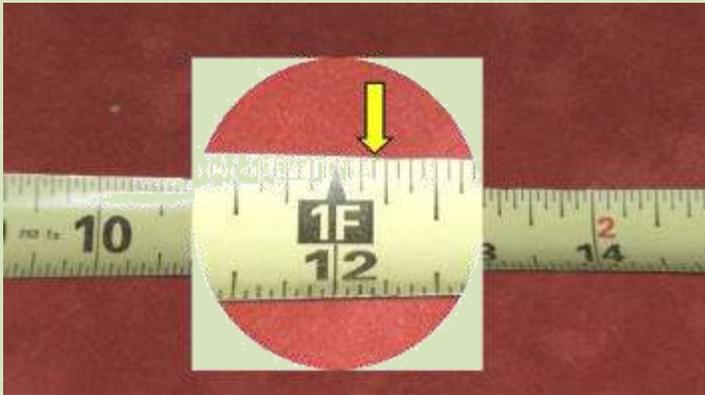
However we must have common numbers in the denominator (bottom numbers) if two dimensions are to be added. Suppose two items are to be measured and a total length presented. If one is 3/4 inches and the other 3/8 inches what is the total length? Quarters and eighths can not be added directly. It is best to convert all measurements to the largest denominator. Therefore 3/4 becomes 6/8 (remember the numerator and denominator can always be multiplied by the same number which is really multiplying the fraction by 1.) The result is 6/8 + 3/8. The picture left shows the answer graphically. But let's get the answer using math. To add fractions 6 of the eight parts are being

added to 3 of the eight parts. So only add the numerator values (top numbers.) Therefore 6 + 3 = 9 or 9 eighths. Stated as a fraction, 9/8. Whenever the numerator is bigger than the denominator the numerator can be divided by the denominator to change to a whole number and possibly a fraction remainder. In this case, 8 goes into 9 once with one left over or 8/8 + 1/8 or 1 1/8 inches. This mark can be seen on the ruler as one space after 1 inch. There would be nothing wrong with saying the answer was 9/8 but suppose the result was 13 inches and 3/8 inches. It could be stated as 13 \* 8 or 104/8 + 3/8 or 104 + 3 = 107/8. However if it was necessary to measure using that dimension it would be a lot of 1/8's for someone to count!



A 1 inch ruler mark could also be split into 16 segments. This is a common way to make a ruler or tape. These smaller marks are still easy to read (compared to splitting it into 32 parts as is done with some steel rulers.) The picture left shows this segmentation with the 1/8 inch marks and the 1/4 inch marks shown as longer red lines.

The 1/16 inch marks shown in black are the shortest. This makes it easier to read quickly.



A tape measure is the same as a ruler except it is longer and flexible. There are also some interesting things to note about most metal tapes. The picture left is a magnified section of a ruler. This ruler is segmented into 1/16ths or 16 segments in an inch. It is also labeled in feet as well as inches. If a measurement is to be made to the

yellow arrow it is located at the 12 inch or 1 foot mark plus 3 spaces. therefore there are 12 inches and 3/16 inches from the end of the ruler to the yellow mark. The mark is said to be 12 and 3/16 inches or 1 foot 3/16 inches-both would be correct.



There are a few other things that should be understood about a tape measure:



As seen in the picture above there is a metal tab at the start end of the tape. It is usually attached with two rivets. However it is loose. **Do Not** tighten these rivets with a hammer! The tab is loose for a reason.

If you're making what is known as an "inside" measurement (picture left) after the tape is locked in position (with black button on top) the tape is pushed with a slight force into the part to be measured. The tab moves in toward the ruler and provides an accurate measurement by properly positioning the zero location.

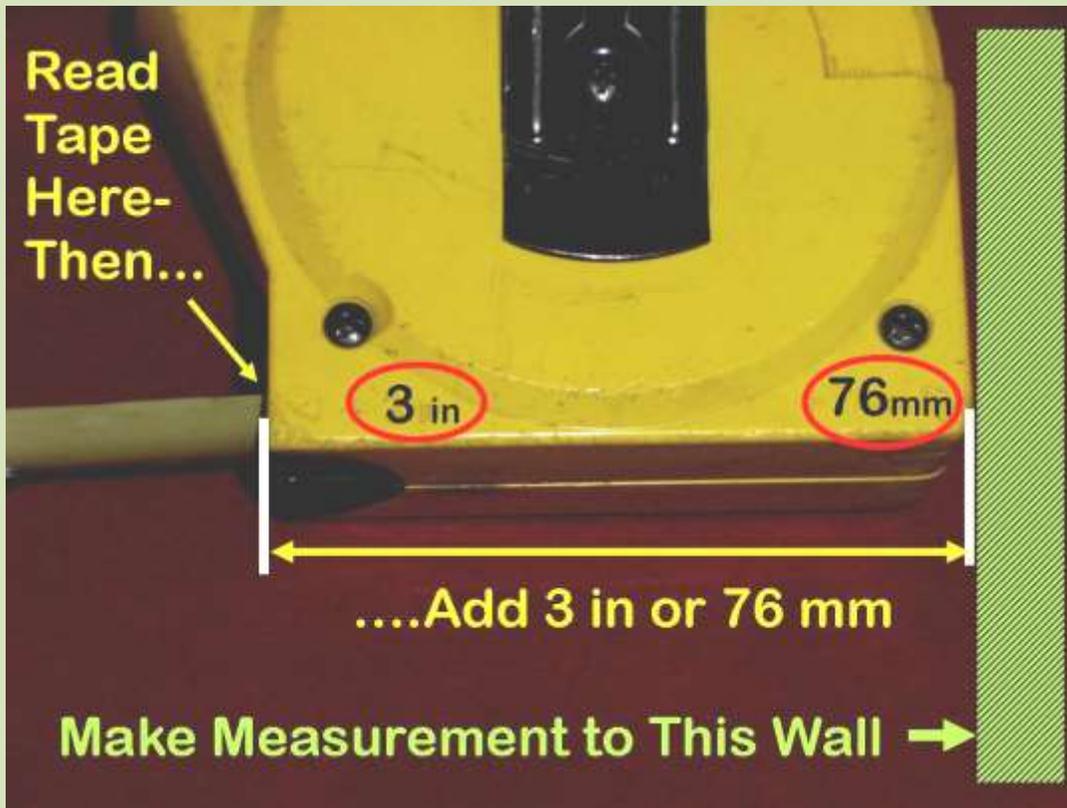
Inside Measurement

In the photo right the tape is being used to measure from the outside edge of an item.



The tape is pulled slightly away from the edge being measured and the tab moves slightly to the left in this case. It moves the thickness of the tab so that the zero point is now on the inside or from the photo the right side of the tab. This places the zero location as necessary to have it measure properly.

Outside Measurement



Another item that is often included on most tape measures is the exact width of the tape holder and it is printed on the side of the body. In the picture above it is shown as 3 inches. (it is also shown as 76 mm which is the approximate metric equivalent.) If the distance between a door jam was to be measured, for example, the tape could be placed in the space, pushing the end slightly into one door jam as defined above to have the tab properly positioned. The back of the tape holder is placed against the other side of the

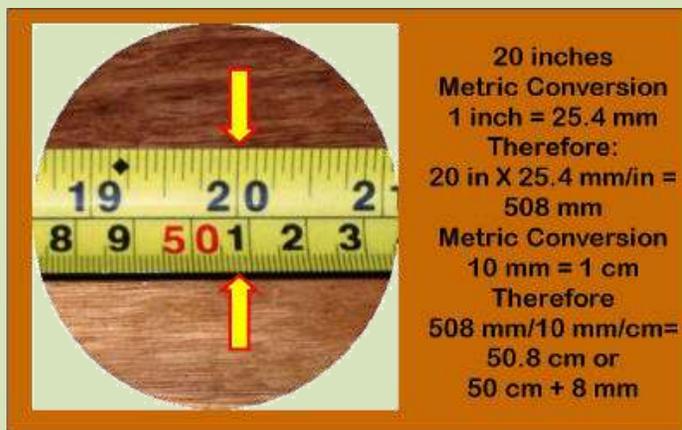
door jam. The tape could be read at the front (see “**Read Tape Here**” in above picture) and in this case add 3 inches to account for the tape holders body size. So if 33 and 9/16 inches was read then the actual dimension would be 33 + 3 added so the final dimension would be 36 and 9/16 inches. Now if the ruler was only 2 1/2 inches wide then the actual dimension would be 33 and 9/16 plus 2 1/2 inches. The whole inch measurements could be added, therefore 33 + 2=35. However to add 9/16 to 1/2 requires stating the 1/2 as 8/16 inches. Then 9/16 + 8/16= 17/16. Since the numerator is larger than the denominator we can divide the numerator by the denominator and obtain 1 with 1/16 left over. Then the final dimension is stated as 33+2+1 and 1/16 or 36 and 1/16 inches or dividing 36 inches by 12 in/ft = 3 feet 1/16 inches.



**Metric:**

Metric Units (now called SI for international Standard) are used exclusively by about every country in the world **accept the US!** Many items such as cars and trucks made and purchased in the US today use SI dimensions, bolts etc!

Metric or SI is actually a simpler system and does not use fractions! All units are in 10ths. The basic length measure is the meter (slightly longer than a yard.) The preferred unit smaller than a meter is a 1000th of a meter called a millimeter (the abbreviation is mm.) 100rdth of a meter is called a centimeter (abbreviated as cm). A cm = 10 mm's. Everything is expressed in 10ths or multiples of 10. The ruler in the above left picture is dual dimensioned; it shows inches on top and metric on the bottom. The top is segmented in 1/16th of an inch with the number of inches displayed. The metric is labeled centimeters with segments in millimeters.



The picture left shows a conversion from 20 inches to metric. The ruler has both US units and metric units. As noted, 20 inches must be multiplied by the conversion factor of 1 inch = 25.4 mm. Therefore 20 inches = 508 mm. Then 508 mm divided by 10 mm/cm = 50.8. Note all we have to do to divide by 10 is move the decimal over 1 place. That yields 50.8. Or 50 cm and 0.8 cm. But a cm is 10 mm. So it could be written as 50.8 cm or 50 cm + 8 mm.

**Rounding the Converted Number:**

The thought process needed when rounding is often bypassed when using a calculator! For example, if someone states a value is an inch, what are they referring too? If they are saying how far to place a knife next to a dinner plate when setting a table, their intent is about an inch not precisely an inch! Therefore the SI equivalent is 25 mm not 25.4 mm which is the conversion factor referred to in the table below. Usually providing the answer in the same number of digits produces the proper answer. That approach typically assumes the digit after the last significant digit listed is about 1/10 of that value. For a machined shaft, dimensions are usually given defining the allowable tolerance, i.e. 1 +/- .001 inches clearly defining the precision intended. That converts to a minimum value of 1-.001 = .999 inches. Converting to metric produces a value of 25.3746. Using the rule of rounding to the same number of significant digits would round to 25.4 rounding 3 to 4 since 7 is the figure following. However, that converts back to 1 inch! If 4 digits are used that converts to 25.37 since the 4 following the 7 is <5. Converting back yields 25.37/25.4 = the correct 0.999. In this instance, 4 digits are needed to achieve the correct precision of the stated intended minimum dimension. If all 6 digits from the calculation were used, the machinist would have to use a more precision device to make and measure the shaft than was intended!

Below Are Some Common Welding Metric (SI) Conversions

<b>Common Welding Metric Conversions</b>		
<b>To Convert From:</b>	<b>Multiply by</b>	<b>To Get This Metric Term</b>
inch (in)	25.4	mm
foot (ft)	305	mm
foot (ft)	0.305	m
Inches per minute travel (ipm)	0.42	mm/sec
Impact ft-lbs	1.36	Joules
pound (lb)	0.454	kg
ft <sup>3</sup> /hr (CFH)	0.47	L/min
pressure (psi)	6.9	kPa
strength (psi)	0.0069	MPa
area (ft <sup>2</sup> )	0.093	m <sup>2</sup>
volume (in <sup>3</sup> )	1640	mm <sup>3</sup>
heat input (J/in)	39.4	J/m

**Topic F: Calculate Shielding Gas Waste**

The table below provides a way to estimate MIG shielding gas waste. The data needed can be obtained from purchasing or your supplier of wire and shielding gas.



Use purchases over a period of 6 months to a year to avoid introducing errors due to variable amounts of inventory.

Notes: 1) If you're using CO<sub>2</sub>, it probably is purchased in pounds. You'll need cubic feet (CF) in the calculations; there are 8.74 CF per pound of CO<sub>2</sub>; 2) Argon is usually sold in CF or in 100 CF- if you are purchasing Argon in Liquid form you may be purchasing it in gallons. If so there are 113 CF of Argon gas when measured at 70 deg F and 1 atmosphere in each liquid gallon; 3) If the welding wire purchase records are only kept in dollars, you'll need the cost per pound. If needed, ask your supplier, they keep the data in a form that you can use directly.

TYPICAL SHIELDING GAS TO WIRE PURCHASE RATIO			
Wire Type	Size	Typical Lbs/hr	CF Gas/ 1 lb Wire Purchased
Solid	.035	3.5	10 CF
Solid	.045	7.0	5.0 CF
Cored	.035	6.5	5.5 CF
Cored	.045	7.5	5.0 CF
Cored	1/16	11.0	3.5 CF
Cored	3/32	14.5	2.5 CF

Compare the typical values in the above table with your usage.

Example: You purchased 46,000 lbs of 0.045 solid wire in the past 6 months and during the same period 610,000 CF of Argon and CO<sub>2</sub> combined:

1. Multiple the value from the far right column in the above table times the wire purchase amount; 5.0 CF/ 1 pound X 46,000 lb of wire purchased = 230,000 CF of gas you should have purchased.
2. However, you purchased 610,000 CF of gas. Therefore 610,000 – 230,000 = 380,000 CF was wasted or 380,000 Wasted / 610,000 Purchased = 62% Gas Wasted!

If you use several types of wire, treat each individually and add the total gas requirements.

See more Information at: [http://netwelding.com/Simplified\\_Gas\\_Waste\\_Estimate.htm](http://netwelding.com/Simplified_Gas_Waste_Estimate.htm)

## Dealing With Percentages:

Reviewing a fabricators test measurement of Gas Flow and Savings when using our patented Gas Saver System shows ways to deal with percentages:

### Texas Truck Storage Box Manufacturer Welds 2.7 Times More Parts with Gas Saver System; a 63% Gas Savings



A Texas based manufacturer of various types of truck storage boxes purchased one of our patented 25 foot Gas Saver Systems (**GSS**) (WAT- FB25) to check for shielding gas savings. They picked a repetitive job, welding doors, and started with a full cylinder of gas. Welding with 0.035 solid wire MIG, using their standard gas delivery hose, 236 doors were completed with that cylinder. Putting on a new cylinder and the **GSS**, with no other changes, 632 doors were welded before the cylinder was empty! That is  $632/236 = 2.7$  times more parts.

The gas savings can be stated several ways. In the base test, with the normal gas delivery hose, 300 CF of gas was consumed welding 236 parts. With the **GSS**, they consumed only  $300 \text{ CF} \times 236/632 = 112 \text{ CF}$  for that same number of parts. Therefore  $300 \text{ CF} - 112 \text{ CF} = 188 \text{ CF}$  is wasted with their normal system! In addition, the **GSS** still provides the proper amount of extra gas at the weld start and maintains the pressure in the hose to automatically compensate for restrictions.

Calculating the gas savings as a percentage of prior use;  $(300 - 112)/300 = 63\%$  **gas savings**. Or said another way it takes  $300/112 = 268\%$  **more gas** to weld the same number of parts. After these impressive results, 25 **GSS's** were purchased for the whole shop.



Stated another way; to weld **632** doors with their standard system they would have needed **2.7** cylinders versus only **one** with the **GSS !!**

After several years of use they needed another 10 **GSS's** for new MIG welders. They asked for more "Magic Hose!"

Note, there are a number of ways to use Percentage. Just be sure they are stated correctly, i.e. the same numbers yielded 268% more or 63% less etc. The same data can be presented both ways.



See More Examples of Reported Gas Savings with our Patented Gas Saver System:  
[http://netwelding.com/production\\_test\\_results.htm](http://netwelding.com/production_test_results.htm)

## Welding Schools

### Minnesota Welding School Installs 30 Gas Saver Systems (GSS™) and Cuts Shielding Gas Use by Over Half

The welding department at a technical college installed Gas Saver Systems from their liquid gas feed piped supply to their TIG welders and to gas mixers then their MIG welders. After three months of use this is what the instructor reports:

*" We went from using 1 Dewar of Argon (liquid gas cylinder) a week to the same size Dewar lasting almost 3 weeks. The companies that sit on my advisory committee are becoming very interested in this upgrade. I will keep you posted."*

**See more information about what can be done to reduce gas waste in schools at:**

[http://netwelding.com/Weld\\_School.htm](http://netwelding.com/Weld_School.htm)



Welding schools can save a great deal of wasted MIG shielding gas by using our patented Shielding Gas Saver System (GSS.) Picture shows welding instructor, Sue, holding 25 GSS ready for installation at Florence Darlington Technical College.

The reasons for a great deal of gas waste in schools are many tack welds and short welds are made. In addition, students often inch the MIG wire to cut off the end to get a good arc strike. Even when just inching the wire to cut off the end; the following is what

happens to the shielding gas supply system that creates a great deal of gas waste:

1. Assume a common regulator/flowgauge is being used to set shielding gas flow (picture right.) When welding, the gas pressure in the gas delivery hose from regulator/flowmeter to welder will have about 4 to 7 psi.
2. When welding stops the gas solenoid in the welder or wire feeder closes and the pressure in the hose will quickly rise to the regulator pressure often about 60 psi for normal flow rates. This stores excess gas to be in the hose. How much? The amount of gas stored is proportional to the absolute pressure or  $60 \text{ psi} + 15 \text{ psi} = 75 \text{ psia}$  (absolute.)
3. When welding the pressure will be  $4 \text{ psi} + 15 \text{ psi} = 19 \text{ psia}$ .

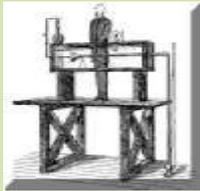


Therefore, the excess is  $75 \text{ psia} / 19 \text{ psia}$  or about 4 times what is needed. Most of this excess gas blasts out of the MIG Gun Nozzle (or TIG cup) when welding starts or even when just inching a MIG wire to cut off the end. Short welds and tack welds, common in schools, make the waste situation very high. The blast of gas also affects the weld start quality since air is pulled into the shielding gas stream causing excess spatter and possible internal weld porosity

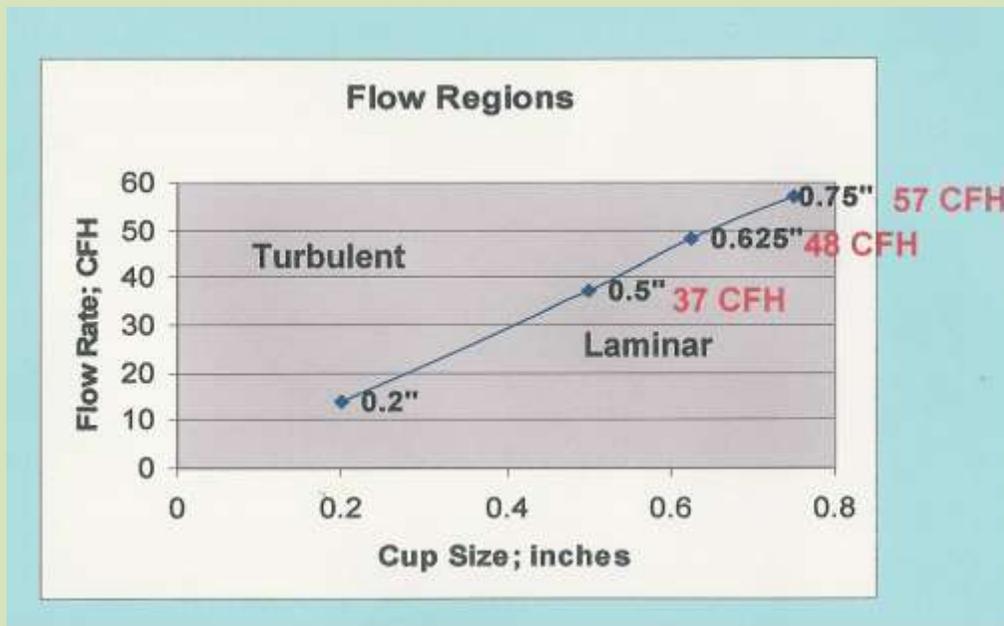
**Topic G: Laminar versus Turbulent Shielding Gas Flow**

High gas flow surge at a MIG weld start causes turbulence in the shielding gas stream. This turbulence causes air to be mixed into the shielding gas stream until the flow rate stabilizes to the preset level. The entrained air causes excess weld spatter and can cause internal weld porosity

The maximum desirable flow rate was published by The Welding Institute (TWI) in England [Wilkinson, M. E., Direct Gas Shield Analysis to Determine Shielding Efficiency. Report of The Welding Institute, Cambridge, England] The exact transition will be dependent on the type of MIG gun or TIG torch used as well as other variables however this study provides some perspective and cautions on the use of too high a flow rate.



In an 1893 technical paper Osborne Reynolds defined in tests there was a very well defined flow level below which a smooth "Laminar" flow was achieved. Beyond that level, a more chaotic "Turbulent" flow existed. He also defined that it takes a short period of time for the gas flow to become smooth and Laminar if it starts in a Turbulent mode. Therefore, at a weld start, the high velocity surge of shielding gas exiting a MIG gun is Turbulent and will take some time to reach the Laminar flow that is needed to eliminate air from the shielding gas stream. Photo left is a schematic of Osborne Reynolds standing next to his flow testing apparatus.



The graph above defines the maximum flow for several common size MIG Gun Nozzles beyond which undesirable Turbulent Flow exists. Not these flows are not much higher than those recommended and unfortunately, below where some welders believe they can set shielding gas flow.

More Information can be found at: [www.netwelding.com/sales\\_literature.htm](http://www.netwelding.com/sales_literature.htm)

**Topic H: A Shielding Gas Leak Means Air is Leaking Back!**

A phenomenon called the law of partial pressures was developed by John Dalton (Born 1766). He found that a mixture of gases behaves as if each were separate. Dalton's Gas Law: He observed that the Total Pressure of a Gas Mixture was the sum of the Partial Pressure of each gas.

$$P_{\text{total}} = P_1 + P_2 + P_3 + \dots + P_n$$

The Partial Pressure is defined as the pressure of a single gas in the mixture as if that gas alone occupied the container. In other words, Dalton maintained that since there was an enormous amount of space between the gas molecules within the mixture that the gas molecules did not have any influence on the motion of other gas molecules, therefore the pressure of a gas sample would be the same whether it was the only gas in the container or if it were among other gases.

Since there is no Nitrogen in a shielding gas hose the partial pressure of Nitrogen in the hose is 0. Since there is 78% Nitrogen in the surrounding air, the partial pressure of Nitrogen is  $14.7 \text{ psia} \times .78 = 11.5 \text{ psia}$ . Therefore, there is a driving force for the Nitrogen to reach equilibrium of 11.5 psia into the hose leak! It will not move as fast as the Argon coming out which may have a driving force of say  $25 \text{ psig} + 14.7 \text{ psi} = 39.7 \text{ psia}$  versus  $0.009 \times 14.7 = 0.13$  in the air. Or a driving force of 39.6 psia which is 3.4 times as much but very little Nitrogen in the gas stream is needed to cause problems.

If welding a material needing a low hydrogen deposit is being used and leaks are present in gas lines, hoses or fittings hydrogen from moisture laden air is entering back through those leaks!

Another way to think about Oxygen, Nitrogen or water vapor going back through the hole in our gas delivery hose where an Argon or CO<sub>2</sub> based shielding gas is leaking out is to consider Dalton's statement.

"The gas molecules are spread very far apart. The Oxygen, Nitrogen or H<sub>2</sub>O vapor will not likely hit an Argon or CO<sub>2</sub> molecule on its journey through the hole! To provide a visualization of how far apart Argon atoms are at atmospheric pressure as they escape from a leak consider: The density of Argon at room temperature and atmospheric pressure is 787 times less than liquid Argon. Therefore, the spacing between Argon atoms in the gas is 787 times larger than in Argon Liquid! Pretty far apart!

Topic I: Calculate Weld Metal Volume (and other formula)

You Can Start From Basics and Calculate Any Weld Volume.

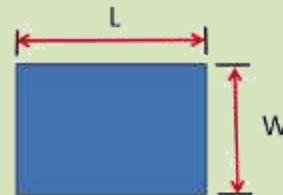
First some formula to calculate Area:

The basic formula for the Area of Rectangle is:

L (length) \* W (width) = Area (Note: We'll use \* to indicate multiply since that is what is used on a Spreadsheet.)

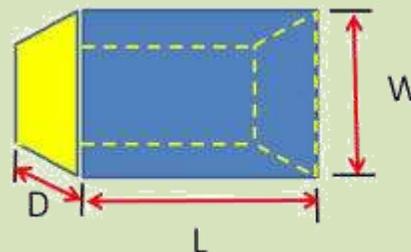
Here is a neat way to check your answer called Dimensional Analysis. Big word but it means checking the dimensions to be sure the result is what you are looking for and helps to be sure your formula is correct:

In this case: L inches \* W inches = Area inch<sup>2</sup> (Since in \* in = in<sup>2</sup> )



Dimensional Analysis verifies you correctly multiplied in \* in and got in<sup>2</sup>

Note: a Square is a special case of a rectangle where both sides are the same so the area can be stated as one side times itself or Area = S<sup>2</sup> (Length of a side squared)



Let's now define the Volume of a Rectangular Block.

W in \* L in \* D (Depth) in = Volume in<sup>3</sup>

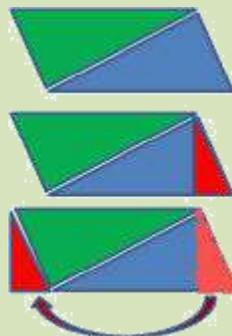
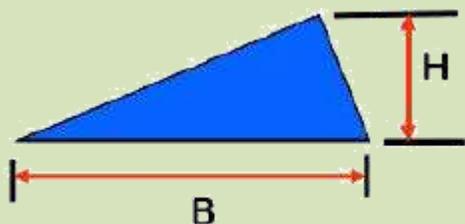
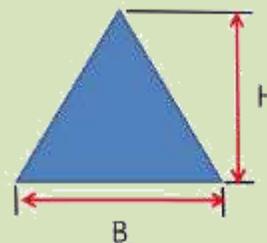
We multiplied three dimensions in inches so got in<sup>3</sup> or cubic inches as an answer.

The following are some formula for calculating the area of additional shapes we'll use to define weld volume in a joint:

For the Triangle on the right: Area = B \* H / 2

Note it is like calculating the Area of a Rectangle and dividing by 2.

This formula works for any size and shape Triangle. Look at the Triangle below left. Below right are picture examples that help



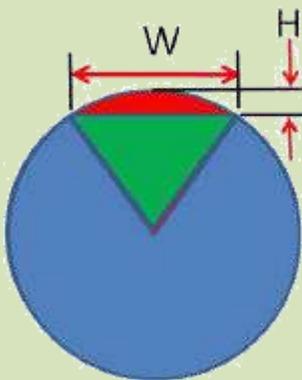
show why this equation works for any shape Triangle:

By duplicating the Blue Triangle and rearranging pieces we can construct a rectangle:

Referring to the three pictures on the right:

1) In the top picture the Blue Triangle is copied and turned upside down. It is shown in Green.

- 2) In the middle picture we make a small **Red Triangle** to create a straight perpendicular side on the **Blue Triangle**.
- 3) In the bottom picture the **Red Triangle** is moved to the left side making a straight side on the **Green Triangle**.
- 4) That makes a **Rectangle** with one side still equal to **B** and the other **H**.
- 5) The **AREA** as defined for a **Rectangle** is **B \* H**. But remember we duplicated the **Blue Triangle** so to get the **AREA** of the **Original Blue Triangle** we have to divide by **2** hence the formula: **Area = B \* H / 2**



**Area of a Segment (Weld Reinforcement)**

This is one **Area** that is often used in calculating weld metal area and volume; it is called the area of a **Circle Segment** and shown in **Red** on the photo left. This is what is used to calculate the area of **Weld Reinforcement**. The accurate way to do this is to calculate the area of a segment of **Radius R** (that is the **combined Green and Red Areas**;) use the length of the **Cord W** (width of weld) and subtract the area of the triangle formed by the **Cord** and **distance** from the **Center of the Circle** and the **Cord (the Green Area.)** This leaves the **Area** between the **Cord** and the **Outer Area of the Circle (Red Area) or Weld Reinforcement** in our case.

However, we would have to estimate the **Radius** of the circle making the reinforcement and the angle of that **Segment**. Not an easy item to estimate. Since we know the weld bead height (or the desired maximum height by code, usually 3/32 or 1/8 inch) and the weld height is much smaller than the weld width we can use a method that estimates the area and is probably better than estimating the radius. The formula is:

Approximate **Area of a Segment (Weld Reinforcement) = (2 H \* W) / 3 + H<sup>2</sup> / 2W**

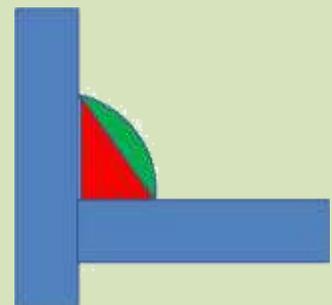
Since weld reinforcement is not a perfect circle, the value obtained is sufficiently accurate for any engineering calculations needed. In fact, since weld reinforcement is not a portion of a perfect circle this approach may be closer to the actual area/volume! **Having checked several typical weld reinforcements dimensions you can use 72% of the Area of a Rectangle for the estimate of reinforcement.**

**With these basic shapes you can calculate the area of almost all welds.**

Look at the following examples of the of weld joints; the weld area can be arranged into **Triangles, Rectangles and Segments.**

To calculate the weld metal volume that must be added to a weld joint you simply multiply the **Area** times the **Length** in the same dimensions. Therefore, if the length is given in feet convert it to inches so all dimensions are in inches. Therefore **Area in<sup>2</sup> \* Length in = Volume in<sup>3</sup>**. Remember dimensional analysis works

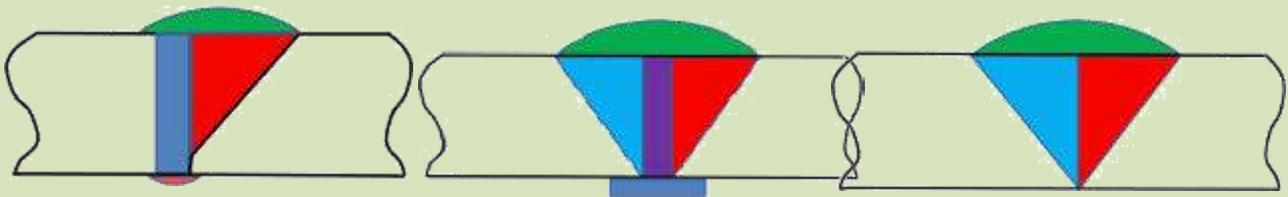
to check your work **in<sup>2</sup> \* in = in<sup>3</sup>**.



Calculate Pounds of Welding Materials Needed:

Now the **Volume** of weld metal you'll need to add is known , how much wire will you need? The following are some material densities:

**Steel weights: 0.284 lb / in<sup>3</sup>; Aluminum = 0.098 lb / in<sup>3</sup>** depending somewhat on alloy and **Stainless Steel 0.29 lb / in<sup>3</sup>** again depending on the alloy.



**So to get lbs of weld metal needed do you just multiply the volume by the density of the material?**

**Is that how much you should purchase?**

**No! You Must Account for Losses.**

For example, when **Stick Welding** the electrode purchased includes flux, you'll also throw away the stub and some of what you're depositing will become wasted spatter. The factor that estimates the amount of welding electrode purchased that deposits as weld metal is called **Deposition Efficiency**. **Stick Electrodes**, as you'd expect, have the lowest values. Depending on the length, type of electrode and the amount of stub being thrown away the **Deposition Efficiency** can vary from as low as 40%, meaning only 40% of what you purchase will become weld metal to a high of 60%. For general calculations you can use 50%.

The following are some values you can use for various welding processes:

**Submerged Arc Welding = 99%** for wire

**MIG Welding with Solid Wire = 97%** with Argon Based Shielding and 96% with CO<sub>2</sub>

**MIG Welding with Metal Cored Wire = 94%**

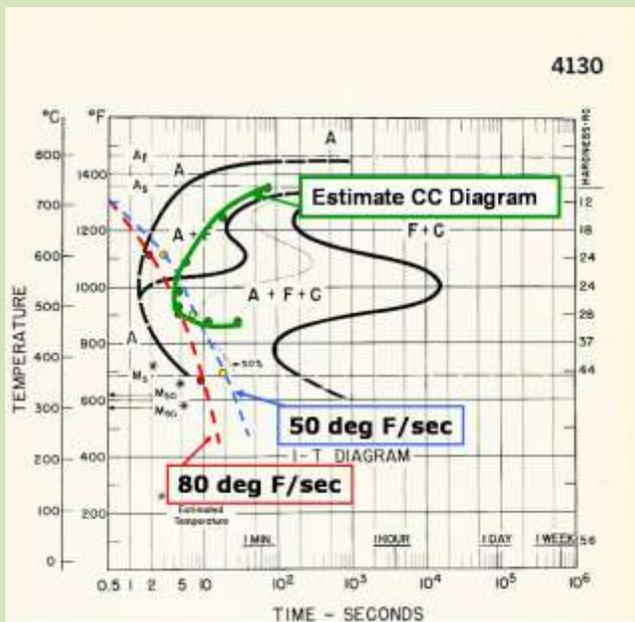
**Gas Shielded Flux Cored Wire Welding = 90 to 93%**

**Self Shielded (Gasless) Flux Cored Wire Welding = 78 to 80%**

**Stick Electrode Welding = ~50% +/- 10%**

Therefore divide the weld metal needed by the **Deposition Efficiency** (as a decimal, i.e. 93% = 0.93) to get how much of the particular filler material being used needs to be purchased.

**Topic J: Weld Cooling Rate**



This Topic provides the math equations that estimate the theoretical cooling rates for TIG welds.

The data is presented so one can see the numbers and dimensions from each part of the equation. TIG process efficiency is shown at 0.57 (57%.)

**Equation Elements and Values**

**R<sub>c</sub>** = Cooling rate at weld centerline; deg F/min

**k** = Thermal Conductivity of metal; BTU/min in deg F

**p** = Density of metal; lb/in<sup>3</sup>

**C** = Specific Heat of metal; BTU/ (lb deg F)

**h** = thickness of metal; in

**H<sub>net</sub>** = Net heat input = BTU / in [V \* I / ipm \* 0.57process efficiency for TIG]

**T<sub>c</sub>** = Temperature which cooling rate is calculated; deg F

**T<sub>o</sub>** = Initial plate temperature; deg F

Welding Cooling Equations from pp 100 Welding Handbook Volume 1, 9th Edition

Thick Plate Equation =  $R_c = - [2 * 3.1416 * k(T_c - T_o)^2] / H_{net}$

Thin Plate Equation =  $R_c = 2 * 3.1416 * kpC (h/H_{net})^2(T_c - T_o)^3$

Calculate estimated cooling rate @ 1100 deg F for thin wall 4130 tube welds:

Tube = .040 in wall; V (volts) = 10; I (amps) = 70; travel = 12 ipm

Using thin plate equation:

$$R_c = -2 * 3.1416 * 0.024 * 0.29 * 0.11 = - 0.00481$$

$$H_{net} = 1.66$$

$$(h / H_{net})^2 = 0.000579$$

$$(T_c - T_o)^3 = 1.07 * 10^9$$

$$R_c = -2981 \text{ deg F / min} = - 50 \text{ deg F / sec}$$

*Also Available for Purchase, an 87 page "Welding Math and Science" Learning Program*

*Includes Basic Metallurgy, including 4130 Chrome-Moly, Basic Math Functions and Basic Algebra*

See: [http://www.netwelding.com/LWM\\_for\\_Welders.htm](http://www.netwelding.com/LWM_for_Welders.htm)