Welding Math and Science

Designed for Welders, Welding Students, Welding Supervisors; To Provide Math and Science Tools for Solving Welding Problems

www.NetWelding.com

Our Welding Math and Science, "Self Study" Leaning Program for Welders, Welding Students, Welding Supervisors, etc **presents the Math and Science information to better understand welding processes and to assist in troubleshooting welding problems.**

It can be used as a "Self Study" program. Each module can be studied separately and in any order based on specific need. An Appendix is provided with topics that can be reviewed at any time as and if needed, such as "Reading a Ruler."

WARNING!

- **Some test procedures suggested for use in this training material could be hazardous. PLEASE READ all material in the notes below this slide.**
- **Shielding gases can leak and IN A CONFINED AREAS COULD CAUSE ASPHYXIATION AND DEATH.**
- **Contact with live electrical parts and ground CAN CAUSE SEVERE INJURY AND DEATH.**

SOME PROCEDURES IN THIS TRAINING MATERIAL COULD BE HAZARDOUS.

READ AND UNDERSTAND ALL MATERIAL NOTES BELOW EACH SLIDE:

Special precautions must be considered when measuring gas flow, installing gas delivery hose, parts, fittings and devices that use them. Some precautions relate to the properties of weld shielding gases. Although these gases are not generally considered harmful under normal circumstances they are usually heavier than air. Thus they will sink to the floor level **AND IN A CONFINED AREA COULD CAUSE ASPHYXIATION AND DEATH**. All connections should be checked for leaks with an approved leak detection solution. Shut off shielding gas supply when not in use.

Some procedures such as checking flows at the MIG AND TIG torch nozzle may involve having the welding power energized. Be very careful since the contact tip and the welding wire will be electrically energized if you use the torch trigger to activate the gas solenoid. Keep hands away from tip and wire or you could be shocked. The welding wire must be prevented from feeding, however do not fully remove it from the torch and feeder since that may increase backflow of gas.   Just disconnect the pressure rolls and test to be sure the wire does not feed. A test is suggested for defining why MIG welding wire melts which could be dangerous if not properly conducted. Be sure to follow all the precautions suggested.

CONTACT WITH LIVE ELECTRICAL PARTS AND GROUND CAN CAUSE SEVERE INJURY AND DEATH.

These statements are **NOT MEANT TO BE COMPREHENSIVE** in regard to the use of the welding products employed. Please carefully read and follow the manufactures instructions. Also refer to publications on safe practices for welding and cutting available from the American Welding Society, 8669 Doral Boulevard Suite 130 Doral, FL 33166 including "Safety in Welding and Cutting" – ANSI/AWS Z49.1.

Module 1
Overview and Summary Outline

Welding Math and Science

Module 1

Module 1 presents an outline of what is included in Modules 2 though 9 as well as suggestions on how to use this Learning Program

INTRODUCTION: When I started my welding carrier I was exposed to the welding science "Bible" at the time, "The Science of Arc Welding" by Clarence Jackson. It is a detailed 29 page series of three AWS Welding Journal Articles that summarized Jackson's 1959 Adam Lecture presented at the 1959 Welding Show. , Clarence Jackson was Associate Manager at the Linde Welding Labs when I started as an Engineer. He had been in welding research and worked on the development of Submerged Arc welding (SAW) when it was in its infancy. Clarence often employed a rigorous Edisonian type approach to his research, changing one variable at a time and making hundreds of welds to validate conclusions. The relationships he developed were often empirical but allowed an understanding of complex relationships. Clarence was my "eyes" under the flux when I started working in the submerged arc welding department. All the other young engineers were working on TIG or the developing MIG process where they could see what was happening in the weld puddle. With Clarence's help and an oscilloscope I soon was able to understand what was occurring under all that "sand!" Clarence Jackson left the Linde Labs to become a Professor in the Welding Department at Ohio State University, and remained a good friend.

Outline of What's Covered:

- Module 1- Overview: How To Use Program
- Module 2- Calculating Weld Metal Volume
- Module 3- Why MIG Wires Melt
- Module 4- Gas Pressure, Volume, Flow
- Module 5- Setting MIG Flow Rates
- Module 6– Weld Cooling Rates
- Module 7- Basic Welding Metallurgy
  - Welding 4130 Chrome-Moly
- Module 8—Charpy Impact Variations Explained
- Module 9—Appendix
  - Reading a Ruler
  - Common Metric Conversions and Proper Rounding
  - Dimensional Analysis
  - Basic math functions, symbols and algebra
  - References

The notes on the bottom of each slide are very important. Please review them. The Appendix can be referenced at any time to assist with some of the topics needed to fully understand a given item.

How to Use This Learning Program

- The program allows scrolling through each page, displaying the upper graphic and the notes below.
- To review each page, scroll down with the scroll arrow on the right side margin.
- The notes below the graphic are very important and explain the key points presented.

Module 1

The PDF Leaning Program allows it's use without the need for other than the free Adobe PDF reader.   Remember, please be sure to read the notes under each graphic.

Printing Each Page

- **One paper copy of the Learning Program may be printed. (note the copyright)**
- **The PDF file is of the Notes Page and the full page will print with the notes.**

Module 1

Printing the program is possible but is dependent on the program used to view the material as to what print options are available. If copies are desired for multiple persons, please contact: WA Technology, by sending an Email: to: Jerry_Uttrachi@NetWelding.com to obtain permission for a modest cost and possible customizing with company or school name.

About the Author

- Mr. Uttrachi has a Bachelors and Masters Degree in Mechanical Engineering and a Masters of Science Degree in Engineering Management from the Industrial Engineering Department at New Jersey Institute of Technology.
- He started his welding career as an engineer in one of the leading welding R&D Laboratories working on the Submerged Arc and Electroslag welding processes. All of the other young engineers in the Lab were working on TIG, and newly introduced MIG and Plasma welding processes where they could see what was occurring, weld puddle formation etc. Submerged arc and Electroslag welding processes required another approach!
- He was fortunate to work with one of the pioneers in Submerged Arc welding, Clarence Jackson who's techniques and insight became his eyes under the flux where welding occurred.
- An oscilloscope and oscillograph also added to his understating.
- Welding Science and Math were keys to this endeavor.

Module 1

Mr. Uttrachi, holds a Bachelors Degree Mechanical Engineering; a Masters Degree in Mechanical Engineering (Emphasis; Behavior of Metals) and a Masters of Science Degree in Engineering Management from the Industrial Engineering Department at New Jersey Institute of Technology. In his graduate degree programs he focused on Statistical Techniques, Metallurgy, Manufacturing Engineering and Engineering Management. Graduate courses included: 1) Advanced Analytical Engineering Statistics; 2) Statistical Inference; 3) Vector and Tensor Analysis; 4) Engineering Reliability; 5) Instrumentation; 6) Principles of Physical Metallurgy; 7) Engineering Metallurgy of Alloy Steels; 8) Light Alloys, 9) Corrosion; 10) Masters Thesis: "Effect of Weld Cooling Rate on T-1 Steel (A517) Weld Metal" 11) Managerial Economics, 12) Industrial Costing and Managerial Control; 13) Advanced Management Engineering; 14) Planning and Management of Industrial Research; 15) Industrial Costs and Managerial Control.

He attended a number of related courses while in industry including: 1) Reliability and Maintainability (by Dorian Shannen @ AMA); 2) MRP/Costing by Ollie White (Ollie White & Associates) [*After working within the MRP manufacturing system for a number of years I now understand that this approach was based on a very poor assumption!*]; 3) MRP II (R.D. Garwood, Inc.); 4) Achieving Process Improvements Through Activity Based Analysis (National Association of Accountants); 5) Louis Allen Management System; 6) TEAM TRAINING techniques were reinforced in the following courses: a) Team Training Skills (Cornelius); b) Team Training Management Update (Don Lyttle); c) Team Skills (AWS); d) Conflict Management (AWS); 6) Quality Quest Leadership (FDTC)

Module 2
Calculating Weld Metal Volume

Welding Math and Science
Learning Program

Module 2

This Module covers how to calculate weld metal volume, in cubic inches and in pounds for steel, stainless steel and aluminum.

What's Coved in Module 2

– How to determine weld cross section areas for typical welds.

– How simple geometry allows defining various weld volumes shapes and how to adapt a few simple areas to fit any weld joint.

– A simple way to estimate weld reinforcement

– Calculating weld metal needs in pounds from cross section area and process efficiency

Module 2

Methods are defined for calculating the weld area for most any weld joint. The area is easily converted to the weld metal needed by using the metal density and the efficiency of each process, i.e. how much metal purchased becomes actual weld metal versus spatter and flux.

Calculate Area of Various Weld Cross Sections

- Some basic formula's allow calculating the area of various shapes.
- A few shapes can be combined into most weld joint configurations.
- Calculating the areas of each, adding them together, then multiplying by the weld length defines the weld volume.
- Knowing the volume and the material density (several will be provided) allows calculating the weld metal needed in pounds.
- Knowing the welding process efficiency allows defining how much welding material is necessary to purchase.
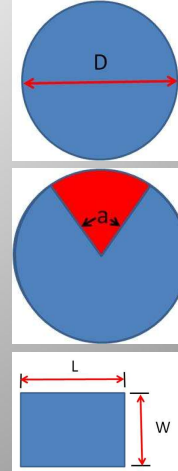
Module 2

Before stating this module you may want to review several sections in the Appendix.   Basic math functions and algebra will show how to manipulate some simple equations such as what a squared function means. The symbols used in this course are also outlined. We use those that are employed in computer spread sheets since the use of spread sheets is an easy way to make calculations.

There is also a topic called dimensional analysis that will be very useful in assuring the proper factors are being used. It is a great way to check a result.

First Common Shape: Rectangle

- The area of a rectangle is the length times the width or using spreadsheet nomenclature Area = L * W
- Using dimensional analysis we'll check to be sure the result is correct: Area =
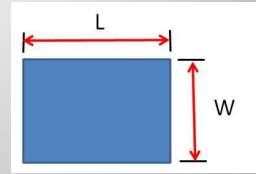
  L inch * W inch = inch * inch = inch^2

- In the bottom picture the length L = the width W. This is a special case of a rectangle and in called a square so the area of a square can also be written as: Area = L^2
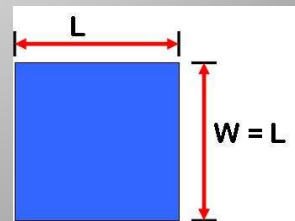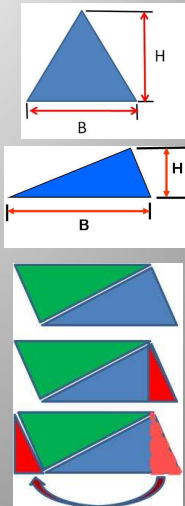
Module 2

One of the simplest areas to calculate is the rectangle. The area is the length measurement times the width measurement. Which one is called length is somewhat arbitrary but the width is sometimes called the distance along the horizon, also called horizontal. Note that is NOT what is shown in the diagram, since as mentioned, it is not important in this case. These dimensions may also be called A & B or X & Y. They simply represent a specific distance to be defined.

The use of dimensional analysis helps check that the dimensions were combined properly. In this case the result we need is area measured in square inches (in^2.) We can forget the actual numbers and just multiply the units, in * in and get in^2 The answer has the correct units. This may seam obvious but the process becomes more useful in more complex equations as we'll see.

Note a square is a special case of a rectangle where each side is the same dimension. Therefore the area of a square is still L * W but since W = L it can also be stated as L^2 Note the 2 in the tem is called an exponent and can be any number or fraction. In this case it is the same as saying L * L. Also note the units are in^2 obtained when in is multiplied by inch.

Another common shape that will be needed is a Triangle. The area is Area = (B* H)/2 Note although not needed, brackets were used to show you multiply B times H before diving by 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 the one on top. Below That picture is a picture example that helps show why this equation works for any shape **Triangle**: By duplicating the **Blue Triangle** and rearranging pieces we can construct a rectangle:

Referring only to the three pictures above on the bottom:

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**

Another Needed Shape: is Weld Reinforcement

- First the area of a circle is needed. A constant defined by the Greek name Pi is used to calculate the area of a circle. The is determined to be Pi (π) (3.142) times the radius R^2

- The weld reinforcement area could be calculated by first defining the area of a segment of a circle, the area in red in the center photo. If the angle "a" is 60 degrees and a circle is 360 degrees that the area of a segment with an angle of 60 degrees is Circle Area $*$ (60 degrees/360 degrees)

- But that is just the start, to obtain just the reinforcement also requires estimating the actual height of the triangle shown in green which is best done using trigonometry which is beyond what we will cover in this text. However there is a better more accurate way, SEE BELOW!
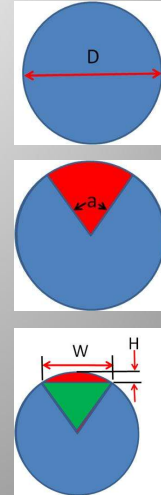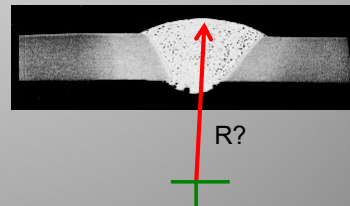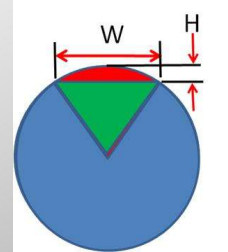
Module 2

Another common shape used in calculating weld area is weld reinforcement. The first step is defining the area of a circle. Archimedes in ~200 BC defined the outer perimeter of a circle was a constant multiplied by the diameter of a circle. He used the Greek name Pi (pronounced like "Apple pie") when defining the constant. For our accuracy purposes the constant can be shortened to 3.142. The area of a circle is determined to be Pi times the radius squared (R^2.) There is a rigorous way to calculate the reinforcement area using a circle segment, shown in **Red** above. If the angle is know, say 60 degrees, then the area of a segment is the area of a circle times 60 degrees/the 360 degrees in a full circle. To calculate the area of a segment of **Radius R (**that is the combined Green and Red Areas in the bottom picture) is to 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.

Another Needed Shape: is Weld Reinforcement

- To obtain just the reinforcement area (the Red area) requires estimating the actual height of the Green triangle. This is best done using trigonometry which is beyond what we will cover in this text. However there is a better, perhaps more accurate way to estimate the weld reinforcement area with an approximating equation or even another way to estimate,
- In fact, since the shape is often not exactly part of a circle our very simple method might be closer! SEE BELOW
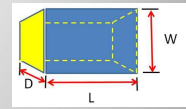
Module 2

The rigorous approach must estimate the **Radius** of the reinforcement and the angle of the segment. Not easy. 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 ^{2} / 2W)**

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 we found 72% of the Area of a Rectangle is close enough for an engineering estimate. In fact since the actual reinforcement is not a perfect geometric size the use of 72% of the area of a rectangle equal to weld width times bead height above the workpiece may be even closer to the actual value! 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 weld **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^2 * Length in = Volume in^3**. Remember dimensional analysis works to check your work **in ^{2} * in = in^3. See Dimensional Analysis in the Appendix.**

Calculate Weld Volume

- Knowing the weld cross section all that is needed is the weld length to get volume. For a rectangle the area = W in * L in is multiplied by the length of weld or D so Volume = L in * W in * D in =X in^3

- Note the units also check: in^3 is proper for volume

- Each of the shapes can be calculated the same way and added together. For the second sketch from the top, there are two triangle (Red and Blue) a rectangle (Purple) and weld reinforcement in green. The other examples are also combinations of the shapes already presented.

- To get pounds of weld metal the density is needed. For steel it equals 0.28 lbs/in^3 Therefore the weight of steel would be X in^3 area x 0.28 lbs/in^3 = X * 0.28 lbs Note the in^3 in the numerator cancels the in^3 in the denominator leaving lbs and the answer.

- Is that how much welding wire/rod is needed? NO, See below

Module 2

To obtain lbs of weld metal needed multiply the volume by the density of the material. **For steel the density is approximately 0.28 lbs/in^3; for aluminum 0.10 lbs/in^3; and for stainless steel 0.29 lbs^3; for titanium 0.16 lbs/in^3**

Is that how much wire/rod you should purchase? No! You Must Account for Losses. For example, when **Stick Welding** the electrode purchased includes flux, the stub you'll through away and 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_2; **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.

Module 3
Why MIG Wires Melt

Welding Math and Science
Learning Program

Module 3

Understanding what causes a MIG wire to melt provides excellent insight on what causes changes in important parameters such as deposition rate and weld penetration.

What's Coved in Module 3

– What Causes a MIG wire to Melt?

– Hint:

- It is not the Hot Arc
- The wire passing trough the Arc
- Radiation from the Arc

– Two key factors cause the wire to melt and have a major effect on other parameters like:

- Weld penetration
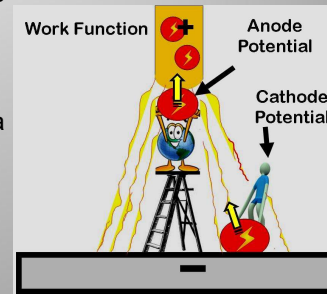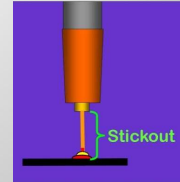- Weld metal deposition rate

Module 3

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:

The first reason is wire Stickout (the distance between the tip and the work piece.) 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 "Sickout."

The second reason the wire melts is that current leaving or entering a surface, be it wire or hot puddle, requires a large amount of energy for the electrons to enter or leave that surface. This energy, generated at the surface, melts the already hot wire. Assuming Electrode Positive this is referred to as Anode Potential (also called Work Function and the units are voltage.) The energy required is equal to Amps * Anode Voltage.

Two Items Are The Major Cause

– What causes a MIG wire to melt?

– The two major factors are shown graphically

- The top sketch is the first, the wire heats due to current passing trough it on the way to the workpiece
- The bottom sketch shows that to get electrodes into and out of a solid takes a great deal of energy. This is called the work function.

– These two factors are the major cause of wire melting

Module 3

The following equation obtained from Reference (1) in Appendix, defines the relationship:

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

Where "a" and "b" are constants and "Wire Stickout" is the distance from the torch 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 of the wire as it passes from the end of the MIG contact tip to the workpiece.

Stickout Change Causes Current Change

If the welding wire feed rate remains fixed and
"Stickout" increases, the welding current decreases

Melt Rate lbs/hr	Stickout inches	Amps
5.5	3/8	200
5.5	1/2	184
5.5	5/8	172
5.5	3/4	162
5.5	7/8	154

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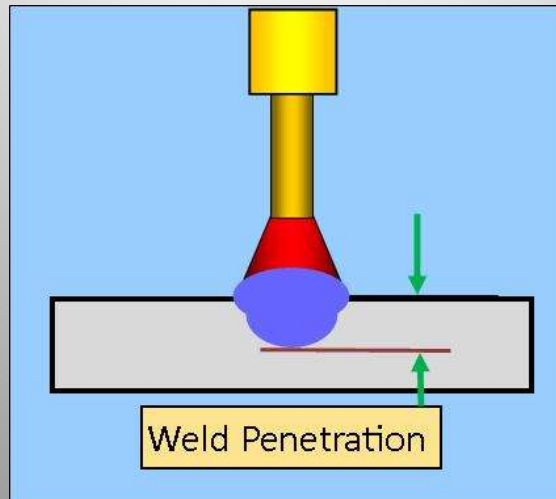All rights reserved. Do Not Copy

Module 3

One major implication of increasing MIG wire "Stickout" at a fixed wire feed speed is as "Stickout" increases the resistance heating increases, the we gets hotter and less current is needed.

The second term includes wire Stickout and the current squared. It is very influential in controlling wire burn-off or deposition rate.

Wire Melting Rate (lbs/hr) = a * Amps + b* Wire Stickout * Amps^2

As seen in the above table for a fixed wire feed speed resulting in a deposition rate of 5.5 lbs/hr the welding current at a short sickout of 3/8 inches is 200 amps. If the Stickout is increased to 7/8 inches the current decreases to 154 amps. The same amount of metal is deposited since the wire feed speed did not change. However the amount of amperage is, in this case , is 23% less ([200-154]/200) The weld metal is deposited with less energy and could cause a cold, unfused area in the weld deposit.

The Second Implication of Lower Current is Lower Penetration

Weld Penetration

Module 3

The Math Equation that defines weld penetration is also very dependent on welding current:

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 an equation defined some years ago by C. E. Jackson in Reference (2) Appendix

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

The Second Implication of Lower Current is Lower Penetration

Stickout inches	Amps	Penetration inches	% Loss
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%

Module 3

The math equation that defines weld penetration is also very dependent on welding current:

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 an equation defined some years ago by C. E. Jackson in Reference (2) Appendix.

Using the penetration equation 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:

Weld Penetration (distance into the base material when making a weld on plate measured in inches) = $K [Amps^4 / (Weld\ Travel\ Speed;\ ipm\ *\ Volts\ ^2)]^{0.333}$

(when putting values in the equation, always calculate the values within the parentheses first, i.e. multiply travel times volts first.

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

Using the previous reduced current data for Stickout changing from 3/8 inches to 7/8 inches shoes the weld penetration reduced from a base of 0.127 at 3/8 inch Stickout to 0.090 when the current reduced to 154 amps at 7/8 inch Stickout. That is a reduction of 29% [(0.127-0.090)/0.127]

Example of Increased Stickout Leading to 20% Lower Current and 40% Reduced Penetration
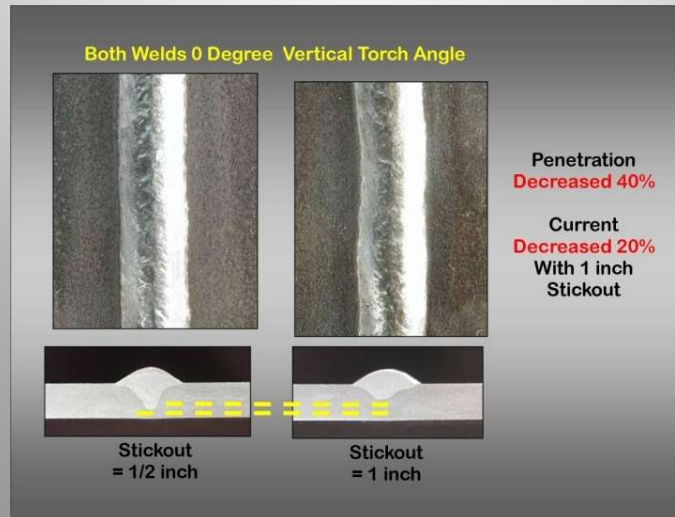
This is an example of increased Stickout from ½ inch to 1 inch causing a 20% reduction in current and a 40% reduction in penetration.

If the weld being made requires full penetration than this increase could cause a lack of fusion defect. The importance of holding a fixed MIG gun contact tip to work distance is emphasized by this example. At times, particularly on thin material this characteristic can be used to advantage. If a joint gap increases and the weld has a chance of burning through, increasing the Stickout will reduce current and may prevent the burn-though. The equation should be used as a guide, it may not give exact values since we are not including material thickness etc. However I have found the relationships are accurate and provide the proper direction.

Module 4
Gas Pressure, Volume & Flow

Welding Math and Science
Learning Program

Module 4

We are often asked what gas pressure should I use for MIG welding. The answer is with the low flow rates used with MIG and TIG welding flow rate is set NOT pressure. It fact the pressure will vary from 3 to 8 psi as the MIG gun cable is bent, spatter builds in the gun nozzle and gas diffuser etc.   Pressure greater than 25 psi are used above a needle valve or small orifice (often 0.025 inches) to drop the pressure and supply the needed floe rate. A phenomena called "choked flow is employed."   However when welding stops the shielding gas continues to flow through the needle valve or orifice and fills the hose with from 25 to 80 psi. This excess pressure and gas volume causes a "blast of gas" at each weld start. A number of solutions have been tried over the years to reduce or eliminate the gas surge at a MIG weld start. This Module explains a simple and effective way to accomplish that objective while maintaining the benefits of retaining higher system pressures to maintain "Automatic Flow Compensation" and providing enough extra gas to purge air from the MIG gun nozzle at the weld start area of moisture laden air. The amount of extra gas provided at the weld start is limited to that needed for the required air purge at a maximum velocity to avoid excess turbulence which pulls air into the shielding gas stream**.**

What's Coved in Module 4

- Relationship: Gas Volume and Pressure
  - Examples
- Relationship: Gas Volume and Temperature
- Gas Blast at Weld Start
- Turbulent Flow Limit
- Peak Flow at Weld start
- Solution to Start Gas "Blast"
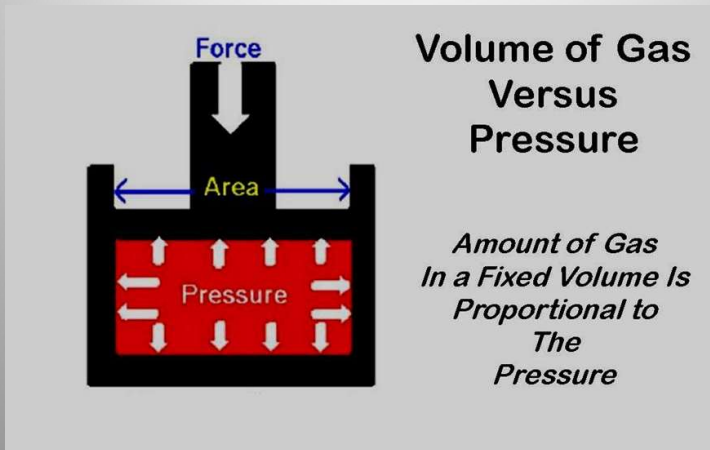
Module 4

This Module discusses the details on a very simple, patented solution to the weld start gas surge problem.

Relationship of Gas Volume and Pressure

Volume of Gas Versus Pressure

Amount of Gas In a Fixed Volume Is Proportional to The Pressure

Module 4

Gas Pressure / Volume Calculations

Understanding the relationship between gas pressure and volume will help when setting shielding 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:

P1/P2 = V1/V2   (Where P, pressure, is measured as absolute pressure = gauge pressure + 14.7 psi at sea level)   Note the air pressure all around us at sea level is 14.7 psi. A typical pressure gauge compares a pressure, as in a tire, with the 14.7 so when it reads 0 it means it is relative to atmospheric pressure.

About 140 years later, around 1800 both Charles and Dalton independently added temperature to the relationship! They defined the following relationship:

V1/V2 = T1/T2 (Where T, Temperature is measured as absolute Temperature in degrees Rankin. Degrees Rankin = Fahrenheit gauge + 460)

Relationship of Gas Volume and Pressure

CHANGE IN GAS VOLUME WITH PRESSURE

Physical Volume	Pressure	Increase in Volume	Pressurized Gas Volume
Large Cylinder 1.8 CF	2500 PSI	$\frac{2500+14.7}{14.7}$ = 171 Times	1.8 CF X 171= **308 CF Gas**
Gas Hose; Depends on ID and Length	Assume; When Welding Stops = 80 PSI	$\frac{80+14.7}{14.7}$ = 6.44 Times	**= 6.44 Times Hose Volume**
+13% Due To Hose Expansion	80 PSI	6.44 + 13%	6.44 X 1.13 = **7.3 Times Hose Volume**

Module 4

First defining the relationship of gas volume and pressure: On the **top row of data** in the above graphic, a typical large argon gas cylinder has a physical volume of 1.8 cubic feet. That is the inside diameter times the length and adding the volume of ½ the sphere at the top is 1.8 ft³. The gas pressure in a full cylinder is typically 2500 psi (lbs/in²) Using the Boyle equation: $P_1/P_2 = V_1/V_2$ where P_1 is 14.7 psi; P_2 is 2500 psi; V_1 is 1.8 ft³ and solving for V_2.

Then multiplying both sides of the equation by V_1 does not change the value then

$V_1 * (P_1/P_2) = (V_1/V_2) * V_1$ But V_1/V_1 in the second term = 1 so they cancel. The equation becomes $V_1 * (P_1/P_2) = V_2$ So we can now solve for V_2 = 1.8 ft³*(14.7lbs/in²/(2500lbs/in²+14.7lbs/in²)) = 1.8ft³/0.00585 = 308ft³

The second row: shows what happens in a shielding gas hose when welding stops. When welding, the pressure is about 4 to 5 psi, which is all it takes to flow the typical 35 CFH (cubic feet per hour of shielding gas.) However when welding stops the gas continues to flow through the needle valve or orifice controlling gas flow and quickly reaches the regulator pressure on the flowmeter or flowgauge. This can be as high as 80 psi. Then using the same equation as above the gas volume in the hose is 6.44 times the physical hose volume.

Looking at the third line of data: we have measured the expansion of a typical1/4 inch ID hose when exposed to 80 psi. It expands about 13% so the gas in the gas delivery hose is 6.44 * 1.13 (and extra 13%) or 7.3 times the physical hose volume. Most of that excess blasts out of the MIG gun at every start!

Relationship of Gas Volume and Temperature

- **Charles and Dalton in ~1800 defined:**
    - **V1/V2 = T1/T2**
    - **Temperatures are measured as absoluter temperature in Degrees R**
    - **Degrees R = Degrees F + 460**
    - **Then 75 F = 535 R**
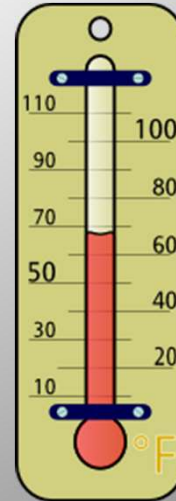
Module 4

Gas Temperature / Volume Calculations

In about 1800 both Jacques Charles and John Dalton independently defined the temperature – pressure relationship. They defined the following relationship:

V1/V2 = T1/T2 (Where T, Temperature is measured as absolute Temperature in degrees Rankin. Degrees Rankin = Fahrenheit gauge + 460)

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

i.e. **V1/V2 =T1/T2**

If T1=75 F than T1 Rankin = 75+460=535 R

Assume T2 = T1 + 20% =90 deg F; then T2 Rankin = 90+460=550 R

V1/V2 due to 20 % Temp Difference =

Then **V1/V2 =T1/T2**= 535/550=0.97

Therefore, 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 a significant factor.

What Happens to the Excess Gas Stored in the Gas Delivery Hose When Welding Stops?

- It 'blasts" out of the MIG gun nozzle at each weld start
- We have measured peak gas flow over 200 CFH
- Even with a large 5/8 inch ID Nozzle that is about 4 times the rate that creates turbulence!
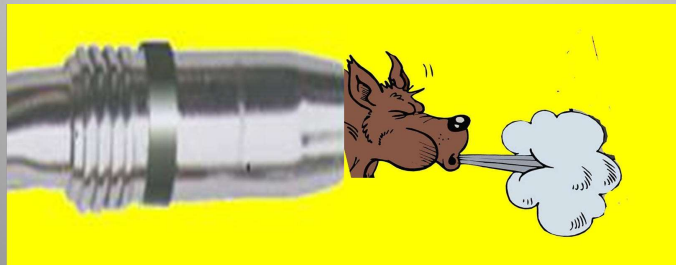
Module 4

The excess pressure and volume in the gas delivery hose that occurs at every weld stop or even if just inching the wire to cut off the end or positioning in in the joint, "Blasts "out of the MIG gun nozzle every time welding starts. The gas exits at a very high velocity. We have measured peak flow exceeding 250 CFH. Typically it is in the range of 200 CFH. This high flow is very turbulent and pulls moisture laden air into the shielding gas stream. This causes excess spatter and internal if not visible weld porosity.

Excess Flow Rate Creates Turbulence

Flow Regions
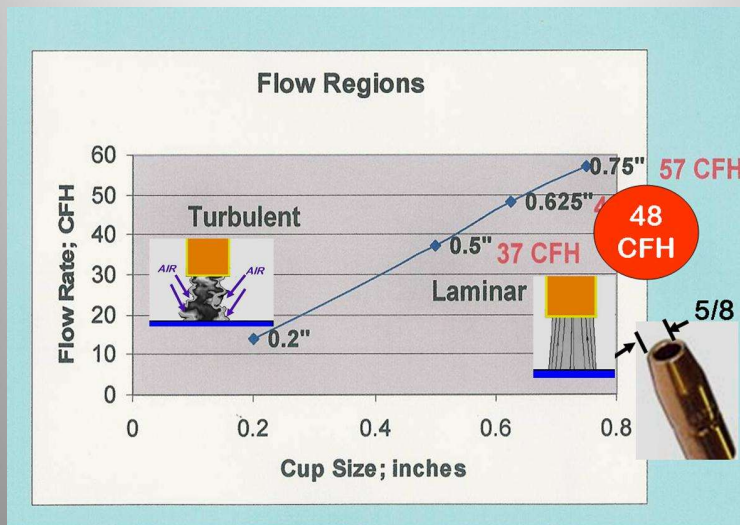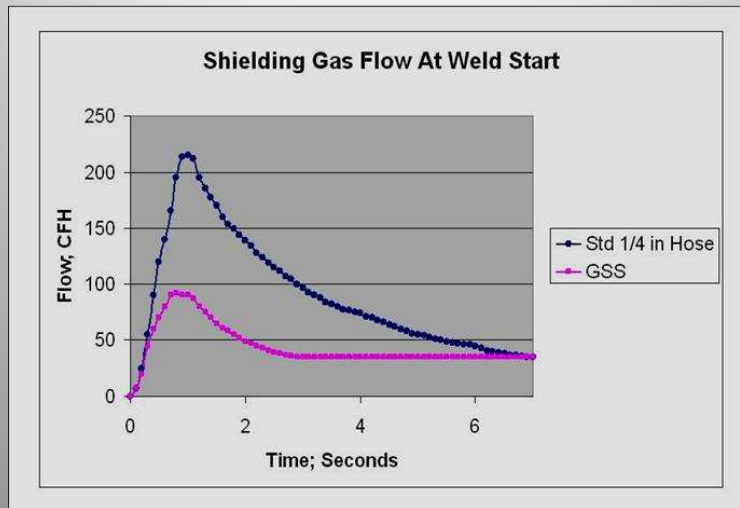
Module 4

High gas flow surge at the weld start causes turbulence in the shielding gas stream. Osborne Reynolds in 1893 defined the parameters that create turbulent versus smooth laminar flow. Turbulence in a MIG shielding causes air to mix 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 if not external weld porosity.   There is little published information on the maximum desirable flow rates for MIG welding. One useful technical article was published by The Welding Institute (TWI) in England entitles, Direct Gas Shield Analysis to Determine Shielding Efficiency (Reference 3 in the appendix.) They report test results where they measured the atmospheric gases in an Argon gas shielding stream. The above graph defines that about 50 CFH flow in a relatively large 5/8 inch ID MIG gun nozzle creates turbulence. In another article published in January 2005 Practical Welding Today magazine , the Manager of Welding R&D for Praxair, Kevin Lyttle, stated: *"In many instances, production site surveys determine that shielding gas flow rates typically are set in excess of 50 CFH. This can contribute to poor weld quality as atmospheric gases are drawn into the arc zone because of excessive gas turbulence."* **This validates the TWI information.**

Unfortunately many believe ***"if some gas flow is good more must be better"*** when it comes to setting shielding gas flow rates! They are mistaken!

**Excess Flow Rate Creates Weld Porosity**

Shielding Gas Flow At Weld Start

Module 4

This graph was made after measuring flow rates in a production weld repair station. When testing our patented Gas Saver System, the welding operator instantly said the system was much better. Knowing he could not see gas waste I asked what he was referring to. He said, his weld repairs were all being Ultrasonic Tested (UT.) He said he knew the gas surge at the weld start was a problem and he was cutting the wire back to the contact tip and starting with the MIG gun held high to give time for the gas surge at the weld start to reduce. He could hear the high velocity. Our tests showed he would have to wait about 5 seconds for the flow rate to reduce below 50 CFH! In addition, Reynolds reported that once turbulence starts, it takes time for it to change to smooth Laminar flow even when flow rate reduces to that level! Note the peak flow rate with our patented Gas Saver System is limited to about 85 to 90 CFH and returns below 50 CFH in less than two seconds for this application.

About 6 months after installing the Gas Saver System the repair welder said he seldom sees any defects on UT where it was very common before! Note the Gas Saver System (*GSS*) still provides sufficient extra gas to purge the gun nozzle and weld start area of moisture laden air.

GSS Maintains System Pressure

- The **Gas Saver System (GSS)** does not alter system pressure so it maintains the automatic "flow compensation" built into normal regulator/flowmeters.
- The small ID volume reduces gas waste.
- A restriction orifice (red insert below) is placed in the feeder/welder end. It is sized to limit only start surge flow rate and allows all normal steady-state flow settings.

44- SPECIAL FITTING   42- STANDARD FITTING

8- DELIVERY HOSE
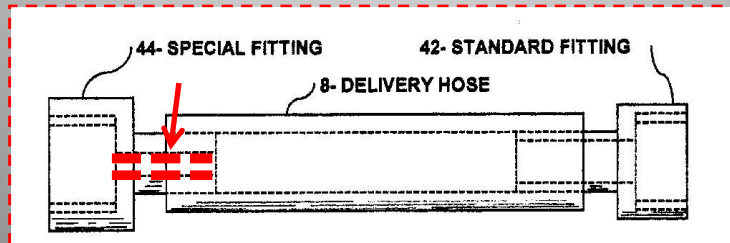
Module 4

The **Gas Saver System (GSS)** reduces the volume of stored gas by about 80%. Therefore there is ~80% less gas waste at each weld start. To assure the start gas surge does not create excess turbulence in the shielding gas stream and to achieve optimum start quality a restrictor is placed in the feeder/welder hose outlet. The size is selected so NOT TO INTERFERE WITH THE STEADY STATE FLOW SETTING. Only the start surge flow rate is restricted and to a sufficiently high level to quickly provide extra shielding gas to displace air in the weld zone and MIG gun nozzle.

How does the **GSS** reduce gas waste 80%? Time for more math! The **GSS** uses an 1/8 inch ID gas hose compared to a standard 1/4 inch ID hose. The volume in a hose is based on the area. An 1/8 inch hose has an area of Pi * R^2. Diameter = 2R. Then dividing both sides by 2 (which does not change the values) D/2 = 2R/2. Since 2/2 = 1 the equation becomes;

 D/2 = R. Then Pi * $(D/2)^2$ This can be written as Pi * $D^2/2^2$ Note you must square both the numerator and denominator. Or area of a circle = Pi * $D^2/4$

The **GSS** hose Area = 3.14 * $0.125^2/4$=3.14 * 0.0039 = 0.0123 in^2 For a 1/4 inch ID hose: Area = 3.14 * $0.250^2/4$ = 3.14 * 0.156 = 0.0491 Then the 1/8 inch ID hose area / 1/4 inch ID hose area = 0.0123/0.0491 = .25 or 25% of the volume. Then 1-.25 = 75% less. Another ~5% volume reduction is created by the peak flow limiting orifice.

Production Examples

The following are production examples of *GSS* gas savings

Truck Body Builder	50% gas savings
Pipe Shop	43% gas savings
Waste Disposal Products	45% gas savings
Structural Aluminum	40% gas savings
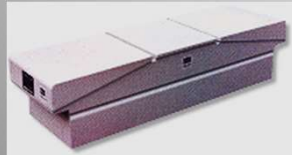
This application was relayed by a manufacturer of truck boxes. They used two cylinders to check gas savings.

- They welded **236** doors with **1 cylinder** and their standard gas delivery hose.
- With the same settings with the *GSS* they welded **636** doors with the other cylinder!

That is a 63% Shielding Gas Savings

Module 4

A number of fabrication shops have provided documented test evidence of the savings achieved. A number have purchased more systems when they have added welders. A truck box manufacturer, after a year of using the 25 *GSS's* they initially purchased added 10 more MIG welders. They called and asked for 10 more "Magic Hose!" It is much more than "magic!" This simple inexpensive solution to a problem that has plagued MIG welding since it's introduction. It is unique and has a US and Canadian patent. Compared to other devices that have been tried over the years it does not alter the "automatic flow compensation" built into MIG gas flow systems since their inception. Spatter build-up in the nozzle and gas diffuser must be compensated when welding. In addition when the MIG gun cable is bent the small gas hose is reduced in cross sectional area. Many MIG guns use the wire conduit passage as the gas hose in the conduit. It can fill with well as wire copper flakes and wire lubricate. As long as pressures are above 25 psi these restrictions are compensated.

Two references define that the average MIG welder uses 3+ times the amount of shielding gas needed. Most due to waste. One Reference (#8 Appendix) shows a large waste occurs because of the excess gas surge at the weld start. The other published reference by a Praxair representative quotes their shop surveys saying the average MIG welder uses 4 to 5 times the volume of shielding gas needed!

Module 5
Setting MIG Flow Rates

Welding Math and Science
Learning Program

Module 5

The understanding of needing extra gas at the weld start was defined in a patent by Stauffer in 1980. This need is discussed and quantified in his patent. Some devices used to eliminate gas waste from the start surge do not properly manage the need for this extra gas resulting in inferior starts. These devices such as orifices placed at the MIG feeder, cause excess porosity and internal if not external weld defects. They may also cause a welder to increase steady state flow in trying to compensate for the lack of extra start gas, which they really can not do.

What's Covered in Module 5

– **Minimum Flow Rates**

– **Typical Flow Rates**

   • **Chart: minimum, Typical, Maximum Flow**

– **Maximum Flow Rates**

   • **Handling wind**

Module 5

Some extra gas is needed at the weld start. In addition high pressure is needed to retain the automatic flow compensation to counter restrictions. That's why MIG and TIG shielding gas flow control systems were designed employing "choked flow" since the 1950's!

Minimum Flow Rates

Plates Help Capture Gas

Butt Welds Require Higher Flow to Equal Fillet Weld
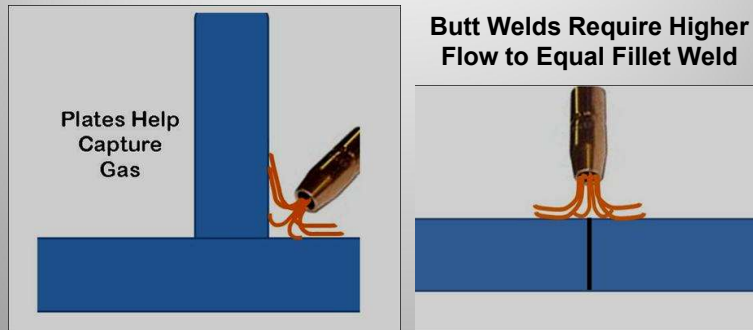
Module 5

MINIMUM FLOW RATES:

A number of factors determine the minimum shielding gas flow rate needed. The MIG gun nozzle size is an important factor. Small ID nozzle sizes require less flow to get quality shielding. Drafts are also very important as is the type of weld joint.

In a low draft environment when making a fillet weld the lowest suggested flows are usable. The plates being welded help retain the shielding gas. Shielding is more effective with the help of the gas retention at these low rates. The vertical member is also effective in providing a natural block for drafts.

Typical Flow Rates

| MIG Gun Nozzle Size Inside Diameter (Wire Size, inches)	Minimum Suggested Flow (1)	Typical Flow Setting	Maximum Suggested Flow (2)
3/8 inch (0.023-0.030)	15 CFH	18-22 CFH	~ 30 CFH
1/2 inch (0.030-0.045)	18 CFH	22-27 CFH	~40 CFH
5/8 inch (0.045-1/16)	22 CFH	30-35 CFH	~55 CFH
3/4 inch (3/32-1/8)	30 CFH	30-40 CFH	~65 CFH

Module 5

TYPICAL FLOW RATE RANGE:

For butt welds there is no vertical plate to help retain the shielding gas. In addition there is nothing to help maintain the gas shield when drafts are encountered. Therefore the gas flow rate needs to increase to assure quality gas shielding and proper weld coverage. The range shown in the above table is typical of that used in industry (or that should be used!) As wire size, welding current and the gun nozzle to work distance are increased, gas flow rates should increase. The minimum flow rates listed are satisfactory for fillet welds where there is no draft.

Maximum Flow Rates
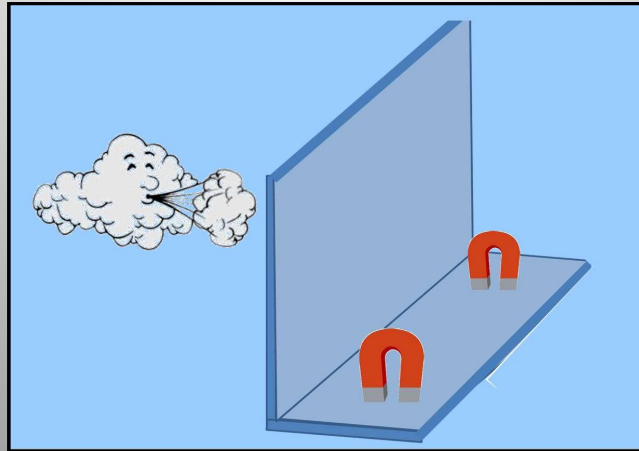
Module 5

MAXIMUM SUGGESTED FLOW RATE:

In the presence of drafts, higher flow rates can be used - up to a limit. It is important to avoid creating Turbulent flow that will pull air into the shielding gas stream. In 1893 Osborne Reynolds defined the flow rates that establish smooth Laminar flow (needed for quality MIG shielding) versus Turbulent flow pulls moisture laden air into the shielding gas stream. Using the data presented previously by The Welding Institute in the UK the maximum suggested flow rates were defined in the previous chart defined to maintain Laminar flow. Reinforcing the maximum flow rate values is unpublished research that defined flow rates needed to handle drafts. In a 4 to 5 mph controlled draft using Argon based shielding gas and a standard 5/8 inch diameter MIG gun nozzle, 45 CFH flow rate had less internal weld porosity as measured by X-ray than 65 CFH flow rate. This reinforces the need to keep flow rates below about 55 CFH with a 5/8 inch nozzle.

During a "best practices for fabricating bridges" tour of Japan, they welded large beams with MIG at the bridge site by erecting a canvas enclosure supported by light weight tubing that blocked wind from the welder.

Above 4 to 5 mph wind, use a windbreak. It can be as simple as positioning your body to block the draft or make a simple sheet metal wind break that attaches with magnets and can be placed close to the weld joint.

Bottom Line

- In general, for Argon and CO_2 or mixtures of these gases setting flow rates higher than about:
  - **27 to 30 CFH with a 3/8 in ID gun nozzle**
  - **37 to 43 CFH with a 1/2 in ID gun nozzle**
  - **50 to 60 CFH with a 5/8 in ID gun nozzle**
  - **60 to 70 CFH with a 3/4 in ID gun nozzle**

  is counter productive, and pulls excess moisture laden air into the gas stream.
- Air in the gas stream causes excess spatter, porosity and inferior properties

Module 5

With solid MIG wires, some Oxygen can be tolerated. The silicon and manganese contained in the wire can combine with the Oxygen to form a silicon oxide or a manganese oxide and avoid the carbon in the weld puddle forming a CO bubble. However published information indicates Nitrogen at levels less than 2% in the shielding gas can cause porosity in single pass welds. It has also been reported that 6% Nitrogen in the shielding gas causes visible surface porosity. Unlike Oxygen, chemically combining Nitrogen into harmless compounds is not possible with solid wire. Elements like titanium can be employed but only at low levels since significant amounts cause embitterment.

Eliminating Oxygen and Nitrogen at the weld start to reduce the possibility of weld porosity and excess weld spatter requires good shielding. In addition to Oxygen and Nitrogen the surrounding air contains Moisture or Water Vapor. The Water Vapor is also be drawn into the arc where it will disassociate into Oxygen and Hydrogen. Hydrogen can cause more than porosity problems. It can cause cracking.

Note for shielding gas mixtures which include Helium these flow rates do not apply. Consult the gas supplier for the specific recommendations for these shielding gases.

Module 6
Weld Cooling Rates

Welding Math and Science
Learning Program

Module 6

This Module presents some equations for determining weld cooling rate. They are more complex equations and are of interest to show how to work with algebra. You may want to review the Appendix before this chapter.

What's Covered in Module 6

- **Weld Cooling Rates Determine Weld and Heat Affected Zone (HAZ) Properties**
  - **Why cooling rates are important, especially when welding high strength steels like 4130 Chrome-Moly**
  - **Cooling rate equations**
  - **View of HAZ widths in welds**

Module 6

This Module discuses the effect of weld cooling rate on the priorities of welds, particularly 4130 Chrome-Moly.

Equations are presented that predict cooling rates in thin and thick plate.

Pictures of macrographs of weld cross sections show HAZ's.

A discussion of temper colors caused by welding heat and a picture shown.

Weld Cooling Rates Define Properties

- The black curves are an Isothermal Transformation Diagram for 4130 chrome-moly

- If 4130 is cooled sufficiently fast to avoid the entering the area within the black lines, starting at about 700 F, brittle Martensite will form.
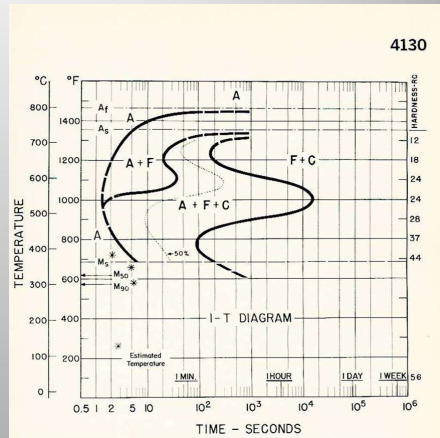
Module 6

This graph will also be presented in our welding metallurgy chapter. Here it will be used to introduce a more complex equation than in any previews module. This is an Isothermal Transformation Diagram of 4130 chrome-moly steel. It is developed by taking a thin sample of material, heating it to about 1600 F then quickly quenching it to a specific temperature and allowing it to transform at that temperature. We'll discuss later how we generated a more practical continuous diagram from this data. It does help define the cooling rate/time to produce a lower transformation product such as Martensite and Banite.

We'll also discuss math equations that allow us to calculate weld cooling rates. These equations were developed by Professor C.A. Adams (See Reference 5 in Appendix)

We'll consider two cooling rates resulting from TIG welds in tubing.

One with a 0.040 wall thickness welding at @ 58 amps, 10 volts, 10 ipm travel

Another with a 0.062 wall thickness welding at @ 79 amps, 10 volts, 11 ipm travel

Weld Cooling Rates Define Properties

- Isothermal Transformation Diagram for 4130 chrome-moly

- The curves in Red and Blue are for TIG welds made in thin material.
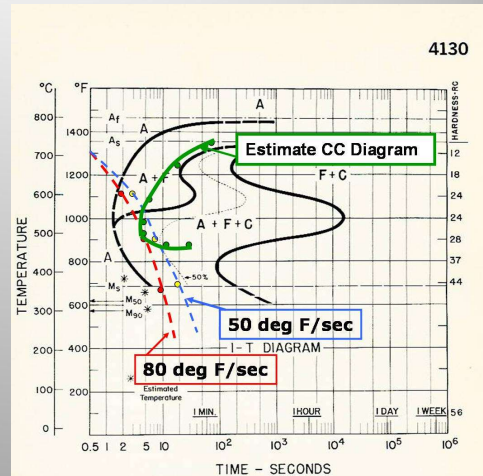
Module 6

The Math Equations data is presented in detail so you can see the values from each part of the equation. As the thickness was increased so was the heat input. A TIG process efficiency of 0.57 (57%) was used which is somewhat higher than the sited in the AWS Welding Handbook reference and errors on the side of predicting a slower cooling rate. The thin plate equation is for two dimensional heat flow and may be OK for a butt weld but Tee fillet welds in tubing will have faster cooling rates. Therefore despite trying to error on the side of predicting slower cooling rates, they are all around the 1/4 inch Jominy bar location. The exact cooling rate will be somewhat dependent on the diameter of the tube as well. However I would expect that perhaps 1/2 way around the tubing TEE joint the cooling rate would be similar to that predicted. As the complete circular weld is made the last part will have a preheat from the weld start. However if a brittle structure is formed in any area and a crack forms, that is sufficient to be a problem.

Weld Cooling Rates Define Properties

- Excessively fast cooling rates in 4130 Chrome Moly tubing can form hard, brittle Martensite.

- Small concave TIG welds made in heavier wall tubes cause fast cooling rates

Module 6

The Units for the Math Equations Functions are:

R_c = Cooling rate at weld centerline; deg F/min

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

p = Density of metal; lb/in^3

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

h = thickness of metal; in

H_{net} = Net heat input; BTU/in [V*I / ipm*.057*process efficiency]

T_c = Temperature which cooling rate is calculated; deg F

T_o = Initial plate temperature; deg F

Weld Cooling Rates Equations

- **Thin Plate Equation**

  - R_c (cooling rate) = $2*3.142*kpC$ $(h/Hnet)^2(Tc-To)^3$

- **Thick Plate Equation**

  - R_c (cooling rate) = $-[2*3.142*k(Tc-To)^2]$ / Hnet

- Details of the factors, with their units are shown below

Module 6

Using the above Thin Plate Equation, and the TIG process data presented previously:

Thin Plate Equation = R_c = $2*3.142*kpC$ $(h/Hnet)^2(Tc-To)^3$:

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

Substituting values in the thin plate equation: $-2*3.142*0.024*0.29*0.11 = -.00481$

Hnet = 1.66 : $(h/Hnet)^2$ = 0.000579 : $(Tc-To)^3$ = $1.07*10^9$:

R_c = -2981 deg F / min = - 50 deg F / sec

Tube = .0625 in wall; V (volts) = 10; I (amps) = 90; travel = 11 ipm

Using thin plate equation: $-2*3.142*0.024*0.29*0.11 = -.00481$

Hnet = 2.33 ; $(h/Hnet)^2$ = 0.000718 : $(Tc-To)^3$ = $1.07*10^9$: R_c = -3700 deg F / min = - 62 deg F / sec

**Tube = .093 in wall; V (volts) = 10; I (amps) = 110; travel = 9 ipm**

Substituting values in the thin plate equation: : $-2*3.142*0.024*0.29*0.11 = -.00481$

Hnet = 3.48 ; $(h/Hnet)^2$ = 0.000713 ; $(Tc-To)^3$ = $1.07*10^9$

R_c = -3671 deg F / min = - 61 deg F / sec

Weld Heat Affected Zone Width

- In steel, a weld Heat Affected Zone (HAZ) is usually considered the area between the weld bead and the thermal line that reached about 1300 F

- On a clean bare steel surface, oxides form, which are of specific colors. These are called temper colors

~2500 F
~1300
HAZ
460 F
500 F
540 F
Temper Colors
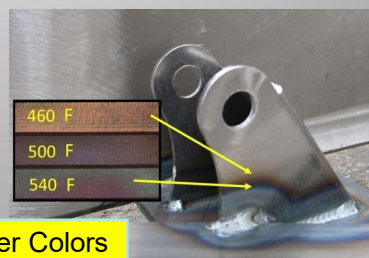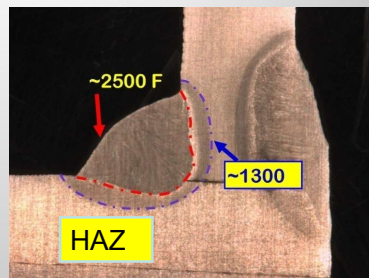
Module 6

Base metal next to a weld is heated from the melting point and lower. We were fortunate to have Professor Adams as a consultant when I worked in a R&D Welding Lab. He helped with a project we had for the Navy. He defined that knowing two isotherms (lines that reached a known temperature) and the distance between was all that was needed to define a weld cooling rate. In the HY-80 steel we were welding, the fusion line and the outer etching boundary were the two temperature isotherms. So a measurement of the width of the HAZ was all that was needed. Two deposits having the same width HAZ by definition had the same cooling rate! A bead-on-plate weld deposit was made with submerged arc at 60 kj/inch; i.e. 500 amps, 30 volts at 15 ipm. That was an allowable heat input for thick plates. The average width of the HAZ was measured and compared with a Plasma Hot Wire surfacing deposit which was in question. Deposits were made with various width Plasma Hot Wire surfacing oscillations to see what reduction might occur with wider widths. I recall there was little benefit in "Effective Heat Input" reduction with wider widths. Therefore for a given power input the linear travel speed was the determiner defining Effective Heat Input with little or no benefit for the oscillation.

A combination of Professor Adams equations and the quantitative approach used allowed the Navy to accept the process with reasonable welding parameters.

Weld Heat Affected Zone Width (cont.)

- Often the HAZ in the base material has lower strength and inferior toughness than the base metal and weld metal.

- Keeping weld heat input low reduces the HAZ width and inferior properties. However if the cooling rate TOO fast a hard brittle material caused Martensite, to form!
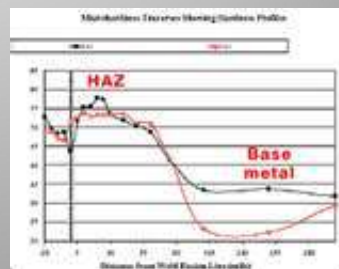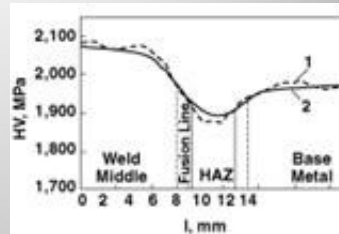
Module 6

Multi-Wire Submerged Arc and Oscillated MIG Weld HAZ

As Chairman of the High Strength Steel Committee of the Welding Research Council, two issues arose regarding "Effective Heat Input." One related to the calculation of heat input in oscillated MIG welding of HY-80 for Navy vessels. The other was how to calculate heat input with multi-wire submerged arc welding. Sub arc and MIG welds were made with various welding parameters. The HAZ area and maximum depth were measured. Summarizing these test results: there was no significant benefit for oscillating the MIG weld. Therefore regardless of the oscillation width (within the practical levels evaluated) the linear travel speed controls the "Effective Heat Input."

For submerged arc welding all HAZ widths were the same supporting that there is no significant reduction in Effective Heat Input for the spaced electrodes. (Note: the spacing's involved where those commonly employed for multi-wire submerged arc welding, i.e. ¾ to 1 ¼ inches.) Therefore the linear travel speed controls the "Effective Heat Input."

Bottom Line

The standard simplified equation for defining heat input of: *(Volts x Amps)/Travel Speed* is an effective measure for most process variations.

46

Module 7
Basic Welding Metallurgy

Welding Math and Science

Learning Program

Module 7

Understanding the basic properties of metals is critical to making quality welded joints. We will focus this discussion to the widely used material, Steel.

What's Covered in Module 5

– Physical strength properties and test
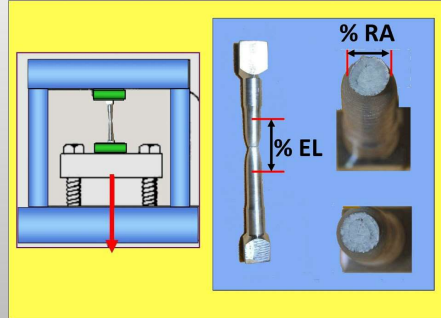– Strength properties of some materials
– Impact properties and test
– Impact properties of some materials

Module 7

We'll start our basic overview with a discussion of the properties of metals. The fact that materials are strong and ductile and that welds can typically be made that match or exceed the base metal is what makes welded metal a very important feature.

Strength of Metals

- A tensile test defines a key property of metals.
- A simple specimen of often used to define how much load can be applied before a material breaks.
- Other measurements can be made from this simple test such as elongation n and reduction in area.

Module 7

The high strength of metals and how they can be formed are very important to their wide use. A simple test is widely used to define strength, called a tensile test. A bar of material is put in a press and pulled until it breaks. The area of the bar before a load is applied is measured and the load when it breaks recorded. Dividing the load, in pounds by the original area of the bar in square inches provides a number, called tensile strength, in lbs/in^2 or abbreviated, psi.

Other important measurements can be made from this test. One value is called yield strength. One way yield strength could be measured is to place a load on the bar and measure how much it stretches when the load is applied. Then remove the load and if the bar returns to its original length, repeat the test with a heavier load. Do this repeatedly until the bar does not return to it's original length. This is called the yield strength. This usually is about 75% to 85% of the ultimate tensile strength for many commercial steels. There is a simpler method of determining this value using an instrument that plots load versus the amount of stretch. Most designs limit the allowable peak loads to well below the yield strength.

Two other important properties define ductility in this test, **Elongation** and **Reduction in Area**. The amount the bar stretches before it breaks is measured and compared to the original length as **Percent Elongation**. For most common structural steels this is typically 20 to 25% or more. The other measure of ductility is **Percent Reduction in Area**. The original bar cross section area is compared to the area when it finally breaks and is reported as percent reduction in area. For structural carbon steel this can be 60 to 65%. These ductility measurements define how much an overloaded part will bend and deform before finally breaking. They also indicate how the material can be formed into shape in a stamping or cold forming operation.

Strength of Metals

| Material	Yield Strength, psi	Ultimate Strength, psi	% Elongation
Carbon Steel	40,000	65,000	22 %
Low Alloy Steel	100,000	115,000	18 %
HY-130 Steel (weld)	135,000	145,000	16 %
Normalized 4130	65,000	95,000	25 %
Q&T Heat Treated 4130 (weld)	140,000	155,000	16 %
6061 T6 Aluminum	40,000	45,000	15 %
304 Stainless Steel	35,000	75,000	65 %

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The above table shows some typical materials to compare the differences in strength and ductility. The HY-130 material was developed for Navy vessels. I worked on that material to develop for submerged arc welding filler materials the early 1970's. The properties are shown for as welded, weld metal (not after post weld heat treatment) to show that weld metal can match the properties of this high quality steel.

4130 is an old higher carbon steel (For welded steels it is considered high compared to more commonly welded steels which have half the carbon content.) It is commonly used in the normalized condition and welds can match the strength with no need for subsequent heat treatment. A quenched and tempered weld is shown of the same material using an electrode designed to match puppetries after heating the final welded assembly to 1600 F, quenching in water and reheating the hardened material to 1000 F called tempering. We'll discuss how and why this material can change it's properties so dramatically when heat treated, later in this module.

Note 6061 aluminum is commonly welded. There are some 7000 series aluminum alloys that can produce strengths equal to steel but they are mostly not readily weldable.

Toughness of Metals

- A Charpy toughness test defines another key property of metals.
- This simple specimen is often used to define how tough or brittle a material is at various temperatures.
- Steel can become as brittle at glass when very cold or if heat treated to a very high strength.
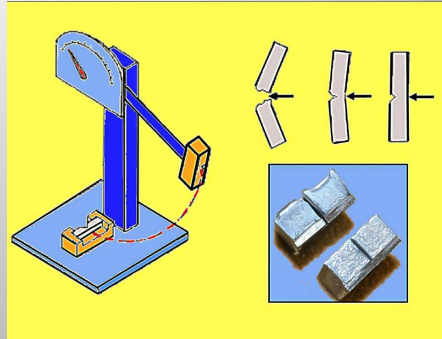
Module 7

In addition to the tensile, yield and elongation of a slowly loaded test specimen a metal is often subjected to impact loads. These loads may be below the yield strength but if at a high impact rate can cause the material to break rapidly with very little bending or ductility. Metal contain many small discontinuities and these can propagate rapidly when a sharp quick load is applied. With steel, as the temperature is lowered, it reaches a level when this propagation can be very rapid and the energy required to cause it to break, very low. A measure of a material to resist this brittle fracture is a Charpy test. For thicker materials a bar about 3/8 inches in cross section and two inched long has a sharp notch machined in one surface. The bar is placed in a fixture and a very heavy hammer is swung to hit the back side of the notched bar. The bar will break rapidly and the hammer continues on its path. By measuring the hammer start height and the height it reaches after it breaks the Charpy bar, the energy required to produce the break is easily defined. A simple pointer is carried with the swinging hammer and leaves the highest point reached on a calibrated scale. The energy is stated in ft-lbs. For example, if a 75 lb hammer is started from a height 3 feet high and reaches 2 foot high after in breaks the Charpy specimen, the energy absorbed is 3 ft*75 lbs = 225 ft-lbs – 2 ft*75 lbs = 150 ft-lbs. Then the Charpy bar absorbed 225 ft-lbs -150 ft-lbs = 75 ft-lbs of energy. These small Charpy samples can be easily cooled to the required test temperature in an cooled alcohol bath.

Impact Strength of Metals

| Material	Yield Strength, psi	Ultimate Strength, psi	Charpy Impact @ 0 F
Carbon Steel	40,000	65,000	40 ft-lbs
Low Alloy Steel	100,000	115,000	50 ft-lbs
Low Alloy Steel	100,000	115,000	@ -50 F =15 ft-lbs
HY-130 Steel (weld)	135,000	145,000	30 ft-lbs
Q&T Heat Treated 4130	140,000	155,000	50 ft-lbs
304 Stainless steel	35,000	75,000	70 ft-lbs
304 Stainless Steel	35,000	75,000	@-150 F 65 ft-lbs

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The above table shows typical materials that are welded to show the various differences in impact strength. Note, even a low alloy high strength steel with 115,000 ultimate strength can have reasonable toughness at -50 F. Even quenched and tempered 4130 (tempered at 1000 F after quenching) can achieve 50 ft-lbs at 0 F. Note stainless steel is very tough at 0 F and holds a high toughness value at even -150 F. Stainless steel is a useful material where low temperature properties are required such as when storing liquid natural gas.

Metallurgy of 4130 Chrome-Moly

- The Green curve is called a Continuous Cooling Diagram.

- When cooling, the time to reach the nose of the curve from ~1300 F defines if brittle Martensite will form. For 4130 chrome-moly steel, about 4 seconds.
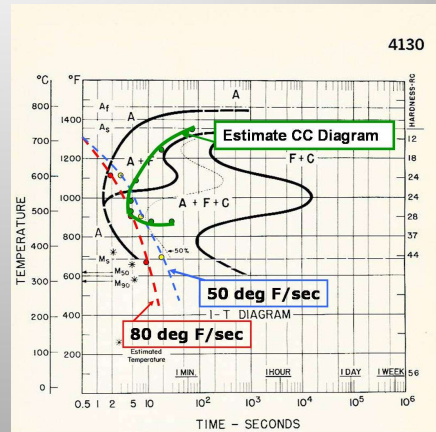
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We already discussed how the black curve, the Isothermal Transformation Diagram, was generated. The green curve on the graph is called a Continuous Cooling Diagram and was generated using a method defined by R. A. Grange and Kiefer (See reference 6 in the Appendix; "Transformation of Austenite on Continuous Cooling and Relation to Transformation at Constant Temperature.") The following are calculated cooling rates for TIG welds made with the following welding parameters:

The Red and Blue curves were developed using equations developed by Professor C.A. Adams (See Reference 5 in Appendix)

The 50 deg F/sec Blue curve represents cooling from a TIG Weld in 0.040 wall tubes @ 58 amps, 10 volts, 10 ipm travel

The 80 deg F/sec Blue curve represents cooling from a TIG Weld in 0.062 wall tubes @ 79 amps, 10 volts, 11 ipm travel

53

Crystal Properties of Steel

- The atoms in solid metals are arranged in crystals, carefully aligned in certain patterns. Above 1675 F sold steel is arranged with an iron atom in every face of a cube. This is called FCC.

FCC Above 1675 F

- When the steel cools the space between atoms recues and there is not room for these atoms in each face. So if cooling occurs slowly they move to the center of the cube, called BCC. The crystal is not stressed and the strength is relative low.

BCC Below 1675 F
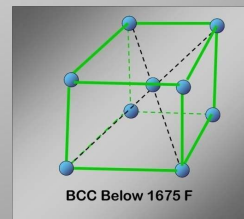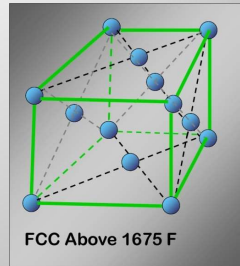
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Iron and steel have interesting crystal properties as the temperature is increased. Above about 1600 F the cubic shaped crystal has an iron atom in each face of the cube. This is called Face Centered Cubic (FCC.) However when the steel cools there is no room for the iron atom in each face. As long as it is not cooled very rapidly the crystal structure will shift and have an iron atom, not in each face, but in the center of the cube where there is more room. That is called a Body Centered Cubic structure (BCC.)

Crystal Properties of Steel (cont.)

- However if the FCC structure is cooled rapidly the crystal distorts and forms Body Centered Tetragonal (BCT) structure. This is highly stressed. If the carbon continent is on the high side (0.30 to 0.40) the effect is even more pronounced.

- As an example, a slowly cooled 4130 steel could have a tensile strength of 85,000 psi. If quenched in water from 1600 F the tensile strength could increase to 250,000 psi

FCC Above 1675 F

BCT Martensite
Below ~600 F
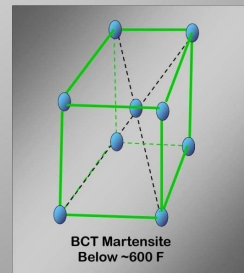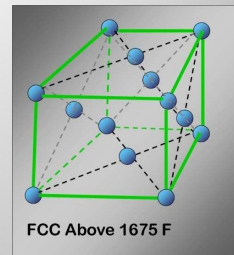
Module 7

However if the steel is cooled very quickly from above about 1600 F, instead of forming a cubic structure the iron atom is forced to the center but the sides of the crystal are not equal, it is not a cube. One side is longer than the other. This is called a Body Centered Tetragonal (BCC.) This is a highly stressed crystal structure. If left in the as quenched condition 4130 Chrome-Moly steel can have a tensile strength exceeding 250,000 psi. This compares to the typical more slowing cooled normalized 4130 which has a tensile strength of about 95,000 psi.

Quenching Produces High Strength but Makes Steel Brittle

- Increasing the strength sounds great and all you need is water! Unfortunately that very strong steel can be as brittle as glass! Hit with a hammer it shatters.
- Damascus swords were reportedly quenched by plunging the hot blade into a warm body! Like quenching in oil that would reduce the cooling rate if the myth were true.
- The option is to reheat the brittle steel, called tempering. The graph right shows a significant increase in toughness when reheated to the proper temperature.

**4130 Q&T Charpy Impact Energy Versus Tempering Temperature**

Impact Energy: ft-lbs — Tempering Temperature: Degrees F
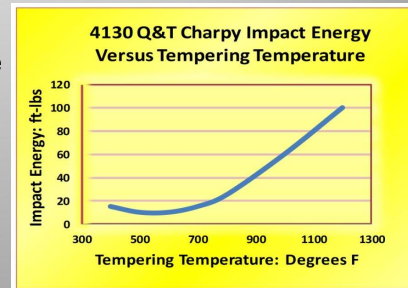
Module 7

Unfortunately that high strength produced with rapid quenching is accompanied with a brittle structure. To produce a practical structural material, the quenched 4130 is reheated. It could also be aided by cooling less rapidly. Damascus swards were reputedly quenched into the body of a slave! This is no doubt a Myth! Reheating the quenched material is the proper way to improve toughness. As noted in the above graph, if quenched 4130 is reheated to the proper temperature (above 600 F to 700 F) the toughness increases. Heating to 1000 F provides a significant increase in toughness to a reasonably high level of 50 ft-lbs. However the strength reduces to about 150,000 psi. This is still a significantly higher strength than normalized 4130 with about the same toughness level.

Other Ways to Improve Steel Properties

- Quenching and small amounts of carbon are one way to increase strength. But most finished welds can not be heated to 1600 F and quench in water or oil!
- Another way is to add what are called alloy ingredients. These can be slightly larger atoms, like nickel and substitute for the iron atom or smaller, like carbon. Both create a stress in the crystal and increase the force needed to have one row of atoms slip over another. Manganese, silicon, moly, chrome and copper are common alloying elements.

Iron Atoms   Replacement Atoms

Substitution Atom:
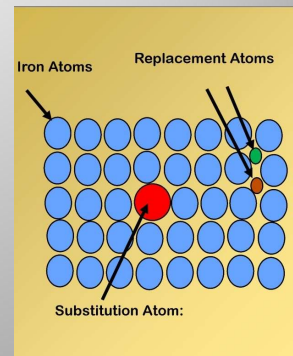
Module 7

The use of small amounts of carbon and quenching from about 1600 F is one way to increase the strength of steel. But most finished welds can not be heated to 1600 F, and quenched in water or oil!

Another way is to increase strength and possibly toughness is to add what are called alloy ingredients. These can be slightly larger atoms than iron, like nickel that substitute for the iron atom. This causes higher stress to be required to have one row (or really plane) of atoms to move over the atoms next to them. It is this movement that causes the material to yield and ultimately break. Both small atoms, like carbon which fit between the iron atoms and the substitution atoms create a stress in the crystal and increase the force needed to have one row of atoms slip over another. Manganese, silicon, moly, chrome and copper are common alloying elements. Nickel, in addition to increasing strength increases toughness. Manganese is a common alloying element and in many situations also increases toughness along with strength.

Some Elements are Not Wanted!

- Some elements, like hydrogen, rapidly dissolve in molten steel but are rejected when the steel solidifies. That causes cracks!
- Hydrogen can come from moisture or oil on the plate to be welded. It can also come from the moisture in air if the gas shielding is either too low (seldom a problem) or too high. For MIG welding more than about 30 CFH gas flow with a small 3/8 inch ID nozzle creates turbulence that pulls in moisture laden air.
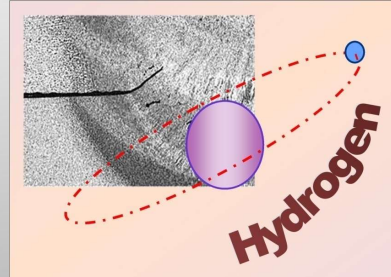
Module 7

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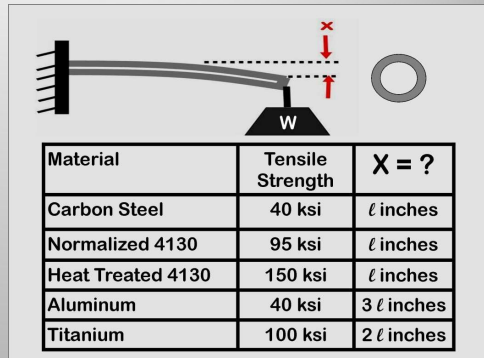
Hydrogen can come from moisture, oil or paint on the plate to be welded. It can also come from the moisture in air if the gas shielding is either too low (seldom a problem) or too high (often a problem!) For MIG welding more than about 30 CFH gas flow with a small 3/8 inch ID nozzle creates turbulence that pulls in moisture laden air.

There are other elements that are bad actors like sulfur and phosphorous. Welding wire specifications, for example, allow a maximum about of these elements of 0.020 to 0.030 percent depending on the alloy.

Another element that is a bad actor and can cause cracks is arsenic. That's an easy one to remember because of it's known bad effects on the human body. Then why are arsenic or sulfur present? The steel mill doesn't add them intentionally but these elements often come along with iron or with scrap from cars etc. They are called tramp elements.

Stronger Steel is NOT Stiffer

- All steel has the same stiffness, i.e. the amount it will bend under a given load
- That exists as long as it is not loaded so much it takes a permanent set.

| Material	Tensile Strength	X = ?
Carbon Steel	40 ksi	ℓ inches
Normalized 4130	95 ksi	ℓ inches
Heat Treated 4130	150 ksi	ℓ inches
Aluminum	40 ksi	3ℓ inches
Titanium	100 ksi	2ℓ inches

Module 7

We are often asked about using stronger steel, like heat treated 4130, to achieve a "stiffer" structure. Even a leading car magazine recently published a statement about employing higher strength to get a stiffer structure. Setting the record straight! All steel has the same stiffness, i.e. the amount it will bend under a given load. That exists as long as it is not loaded so much it takes a permanent set, i.e. exceeds the yield strength. Even then it isn't stiffer it just can bend further. The figure above notes that for given load W (note we didn't say what the load was, it was just represented by the letter W. We're using on algebraic approach!) In this example a tube of the same diameter and wall thickness is fixed to a wall. The load is added and the amount it bends measure (another letter is used, l for the length it bends from where it started.)   In this case for the same load, carbon steel with a strength of 40 ksi (ksi is another term, called kips per square inch, 1 kip = 1000 psi; it makes tables less cluttered!) The same distance is reached with over twice the strength steel at 95 ksi or even 150 ksi! This is a feature of a material called Modulus of Elasticity. All steel has essentially the same value. Of interest, aluminum, which is about 1/ 3 the weight of steel bends 3 times as much as steel! Titanium is about 1/2 the weight of steel and bends twice as much. They are no help in the weight/stiffness issue assuming the same size and shape.

Stiffness Can Be Increased with Large Diameter Tube

- The weight of a tube is directly proportional to its diameter (assuming the same wall thickness.)
- Stiffness is proportional to the diameter cubed i.e. d^3
- So diameter can be increased with a thinner wall high strength steel-right? Yes, but be careful!
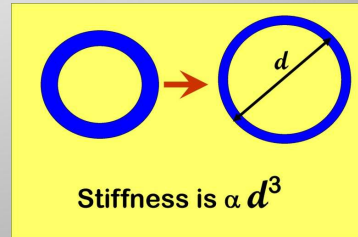
Stiffness is α d^3

Module 7

The why use high strength steel? There is a way to make a structure stiffer, by changing the shape. For a tube, the stiffness is proportional to the diameter cubed (d^3.) the weight of a tube of a fixed wall thickness is proportional to the diameter, d. Therefore the tube can be made large in diameter and thinner and the stiffness can increase and the weight decrease. The following are some examples for steel tubes of how "stiffness" can be increased or weight reduced for the same "stiffness":

· A **3** inch diameter steel tube with an **0.062** wall is **18%** "stiffer" or deflects **18%** less than a **2.5** inch diameter tube with a **0.093** wall thickness and is **7%** lighter per foot.

· A **2.25** inch diameter tube with an **0.062** wall thickness is about the same stiffness and weights **10%** less per foot than the **2** inch **0.093** wall tube.

· A **2.5** inch diameter tube with an **0.062** wall thickness is about the same stiffness and weights **27%** less per foot than the **2** inch **0.125** wall tube.

If the Tube Gets Too Thin it Can Buckle!

- A small defect in a tube that is too thin can cause it to buckle well before it reaches the yield strength.
- This is called "Local buckling or "the crushed bear can effect." if you use all your strength it may be impossible to crush a bear can just pushing on the ends. However put a small depression in the can sides and it crushes easily.
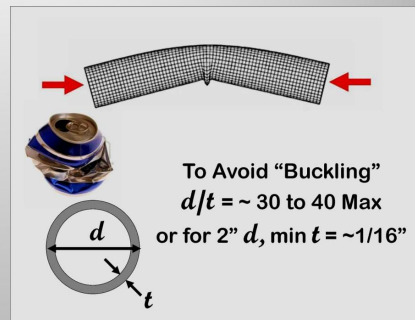
To Avoid "Buckling"
$d/t = \sim 30$ to 40 Max
or for 2" d, min $t = \sim 1/16$"

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The tube wall thickness to diameter ratio must be carefully considered to avoid local bulking. Local Buckling is caused when structural tube wall thickness is too thin compared to the diameter. The Euler Equation defines allowable loads for a column with "Pinned Ends" which is one way to asses the loads in a tubular structure:

Max Load = p^2 E I / l ^{2}

However Local Bucking can occur at much lower loads when the diameter to wall thickness ratio is greater than about 40 to 50 :1. Or a 1/16 inch thick wall tube should be less than 2 1/2 to 3 inches in diameter to avoid this problem. That is only a rule of thumb; circumstances may dictate the use of a more conservative ratio. In fact some references define much lower safe ratios.

This is sometimes referred to as the "aluminum bear can effect." An empty bear car can require a high load to crush if force is applied slowly from both ends. However put a small dimple in the side with your thumb and it crushes under a much lower load. Have you wondered how that is done? Buckling is fine for a bear can but not a race car chassis!

61

Dragster Fails at ~300 mph!

- Dragster frame fabricator convinced NHRA to accept "heat treated" 4130 vs traditional "normalized" 4130
- They used thinner wall tubing because of higher strength
- Although heat treated tubing can have problems in the weld Heat Affected Zone (HAZ,)
- TV New Folks said "Local Bucking" caused the failure.
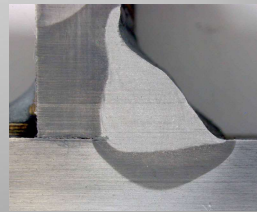
I was asked by an "old time" dragster frame builder, Don Long, to comment on the request one dragster framer producer asked NHRA to approve; using "Heat Treated" 4130 tubing versus the traditional ~95,000 psi "Normalized" 4130 tubing. I expressed concern that the Heat Affected Zone (dark area next to weld in lower Pic) would have reduced strength in Heat Treated 4130 as welded tubing is used in the as-welded condition. That supported concerns Don Long had as well as a University Professor showed in a structural analysis the increased strength was not helpful in the design etc. NHRA did not listen to Don's or other recommendations and approved it's use.

Soon after th dragster in pic above (owned by Don Schumacher) had used this new frame produced by the dragster frame builder and failed in a National Event at 300 mph! The TV news announcers in the next televised NHRA event said the failure was probably due to local buckling.

However John Force used similar "Heat Treated 4130" in a Funny Car. In a test, the car vibrated very seriously from tire shake causing a tragic accident.   In an interview, John said the frame broke in a million pieces. Steel should NOT break in a million pieces! Normalized 4130 is not brittle. Heat Treated 4130 could be as well as it could have much lower strength in the HAZ.

Module 8
Charpy Impact Variations

Welding Math and Science

Learning Program

Module 8

Charpy impact testing is very common and there are minimum values allowed for welding many structures. Bridges, for example may require a minimum of 20 ft-lbs at -20F. However if you're building a bridge in Alaska they may require 20 ft-lbs or more at -50 F.

Charpy Impact Properties Vary

- **Charpy impact property in a multipass weld varied considerable.**
- **One measure of the difference provided some correlation at +10 F with the amount of refined material (that weld metal reheated by a subsequent pass.)**
- **However at -50 F there was wide scatter and no correlation with the amount of refined material.**
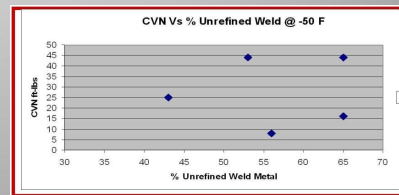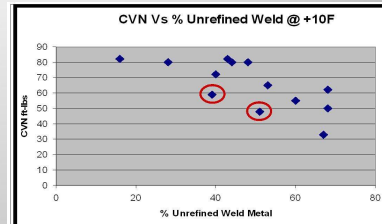
Module 8

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, a Professor at Lehigh University, 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 Charpy 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 some coloration with the Charpy impact level. However at -50F there was no correlation.

64

Charpy Impact Properties Vary

- **Our senior metallurgist postulated that not only was the amount of refined area but in addition it depended on where it was located.**

- **As he noted the center of even a ductile Charpy is stressed in all three directions. Therefore even the ductile refined material was in the center it would not have the positive influence as if were located at the edges.**
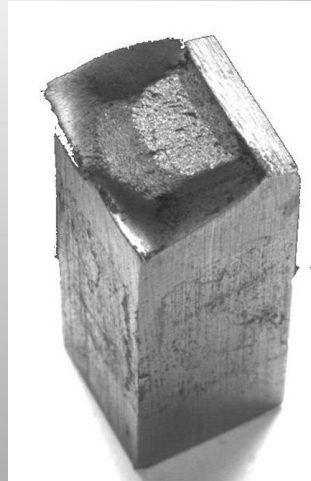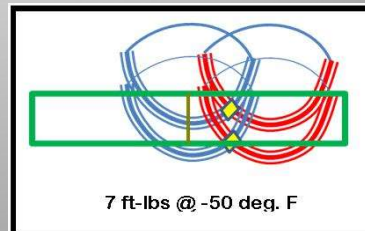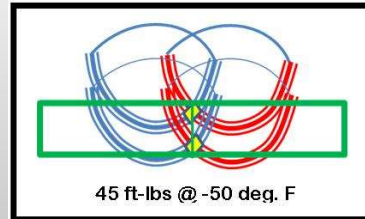
Module 8

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. 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 Dr. Nelson 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 above 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.

Charpy Impact Properties Vary

- **Two Charpys were purposely placed in a wide multipass weld having the same chemistry.**
- **Both had 50% refined material. One had double refined material placed at the edges and produced 45 ft-lbs @-50 F**
- **The other had single refined material placed in the center of the Charpy and had only 7 ft-lbs.**

45 ft-lbs @ -50 deg. F

7 ft-lbs @ -50 deg. F

Module 8

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

Charpy Impact Properties Vary

- **When the doubly refined material was placed in the center of the Charpy test**
- **Both had 50% refined material. One had double refined material placed at the edges and produced 45 ft-lbs @-50 F**
- **The other had single refined material placed at the edges and produced only 17 ft-lbs.**

22 ft-lbs @ -50 deg. F

17 ft-lbs @ -50 deg. F
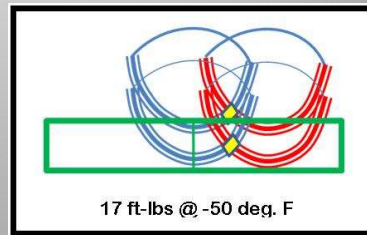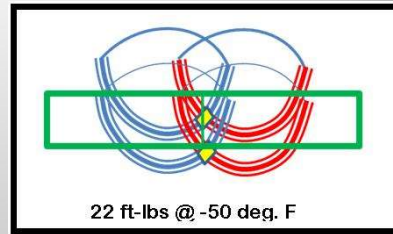
Module 8

A Charpy specimen was placed with doubly refined material in the center of the Charpy specimen: the toughness was 22 ft-lbs, about 1/2 the value that was achieved when that same material was placed at the edges. Placing single refined material at the edges produced 17 ft-lbs versus the 7 ft-lbs when that same material was located in the center of the Charpy.

In general it does indicate 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 than when it was placed in the center of the Charpy. Does this mean you should watch where the notch in the Charpy is placed? No, various codes specify the location where the Charpy specimen must be located. However if the weld bead sequence is properly placed the toughness can be influenced. Some welding filler metal manufactures had made recommendations about placement of weld beads to optimize Charpy toughness. In my opinion that is circumventing the intension of specifications. Cracks will find the brittle areas! This analysis does provide a method of understanding Charpy impact differences.

Module 9
Appendix

1. Reading a Ruler
2. Common Metric Conversions
3. Dimensional Analysis
4. Basic math functions, symbols and algebra
5. References

Module 9

These subjects can be reviewed independently on a needs basis.

Reading a Ruler: Requires Using Fractions

- Reading a ruler in *US Units* requires working with *Fractions*.
- 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.
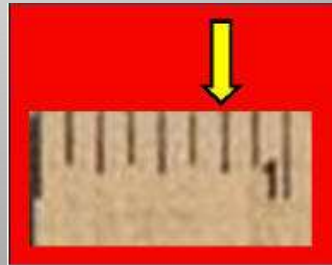
Module 9

Reading a ruler in *US Units* requires working with *Fractions*. If the Metric System was used fractions would not be needed, everything is in 10th. Rulers and measuring tapes are commonly calibrated in feet and inches. Instead of segmenting the feet into 10ths of a foot, it is divided into 12 parts labeled inches.   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 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 above picture 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!

Reading a Ruler: Using Fractions

- Rulers have different length marks making it easier to read. In the top picture the lonest line is at the inch marks, the next longest at the 1/4 inch mark.

- The objective is to use the smallest whole numbers to state a measurement. The yellow arrow is at the 6th of 8 marks from the start or zero mark. We could say it is 6/8ths

- However we can simplify that fraction by dividing top and bottom by 2 and we get 3/4 inches.

Module 9

The top picture shows, counting from the start or zero mark there are 6 spaces or 6/8 of an inch. 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 divided by 2 that would give 6 / 2= 3 for a numerator and 8 / 2 or 4 for the denominator. The fraction would become 3/4. Both 6/8's and 3/4 would be accurate and a person could be told to go cut a steel rod 6/8th of an inch long.   However it would be easier to count 3 of the 1/4 inch marks and get 3/4. It is the same value as 6/8 but with smaller numbers. This is more obvious if the ruler were divided in 16ths. We could say go measure 12/16ths and they would have to count 12 spaces. It is much easier to just count 3 of the 1/ 4 inch marks.

Reading a Ruler: Fractions (continued 2)

- The rule right is marked in inches and the inch split into 8 parts. The segment on the left includes 6 of the 8 parts. It could be simply called 6/8ths as shown.

- It is common to simplify the larger numbers into the lowest number possible. In this case the top and bottom numbers can be divided by 2 which does not change the value: 6/8 = 3/4

- In the bottom picture the inch is split into 116 parts with the 1/8 and 1/4 marks (shown red) longer.
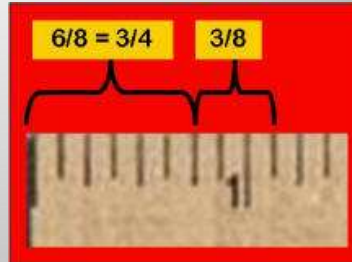
Module 9

Both numerator and denominator could be divided by 2. That would give 6/2 = 3 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 the longest lines are quarters of an inch rather than eighths. The longest lines can been counted more quickly as the 3/4 mark! 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 eights cannot 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. To obtain the answer using math, 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 eights. 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!

Reading a Ruler: Fractions (continued 3)

While most rulers have a maximum of 16 divisions to the inch, some have more. These are usually made of steel and the divisions machined into the surface with paint filling the engraved lines. Beyond a 1/32 it is best to use a dial caliper or digital caliper or similar device. Today these can be relatively inexpensive and are much more accurate than trying to eyeball the small lines on a steel rule. Dimensions on these instruments are displayed in hundreds or even smaller parts of an inch.
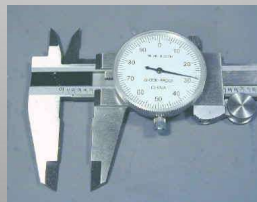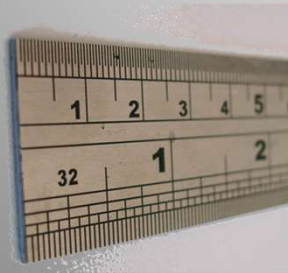
Module 9

While most rulers have a maximum of 16 divisions to the inch, some have more. These are usually made of steel and the divisions machined into the surface with paint filling the engraved lines, these can have 32 divisions in an inch. Beyond a 1/32 it is best to use a dial caliper or digital caliper or similar device. Today these can be relatively inexpensive and are much more accurate than trying to eyeball the small lines on a steel rule, especially one with 32 divisions of even more Dimensions on these instruments are displayed in hundreds or even smaller parts of an inch. When measuring in 10ths there is no need to worry about fractions!

Reading a Ruler: Tape Measure

- A tape measure is the same as a ruler except it is longer and flexible. It is also labeled in feet as well as inches.

- There are also some interesting things to note about most metal tapes. 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.
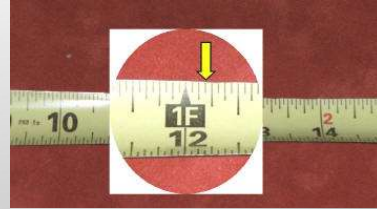
Module 9

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.

Reading a Ruler: Tape Measure Loose Tip

- A tape measure is the same as a ruler except it is longer and flexible. It is also labeled in feet as well as inches.
- There are also some interesting things to note about most metal tapes. 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.

Module 9

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 (top picture) 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.

In the bottom photo 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. 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.

Reading a Ruler: Tape Measure

This combination US SI unit tape has another feature. It has 3 inches and 76 mm printed on the side. That is the length of the side. For an inside measurement the tape can be read (see yellow arrow) and 3 inches or 76.mm added to the measurement. A very useful feature.

Read Tape Here- Then...

3 in

76mm

....Add 3 in or 76 mm

Make Measurement to This Wall →
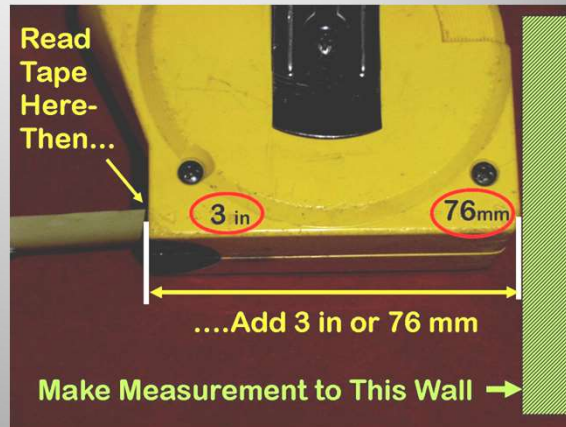
Module 9

Another item that is often included on most tape measures is the exact width of the tape holder and that measurement 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" note 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.

Introduce Metric (SI): Tape Easier in Metric

- A Ruler is a good way to introduce the Standard Industrial measurement system. Unlike the more common US measurement system which breaks a foot into 12 inches and an inch into 8th, 16ths or 32nds, the metric system is like our US money. It s broken into 10ths.
- Like the $1 is split into 100 pennies and 10 pennies equal a dime. There is NO NEED for Fractions!
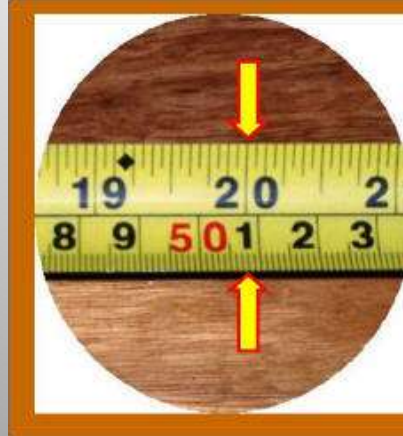
Module 9

Metric is now called SI for Standard Industrial measurement system:

SI measurement is used by about every country accept the US. Many items such as cars and trucks made and purchased in the US today use SI dimensions, bolts etc!

SI is actually a simpler system and does not use fractions! All units are in 10ths. One basic length measure is the meter (slightly longer that 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.

Introduce Metric (SI): Tape Easier in Metric

This ruler has both standard US inches and SI millimeters and centimeters displayed. It is a good way to see the difference.

20 inches
Metric Conversion
1 inch = 25.4 mm
Therefore:
20 in X 25.4 mm/in =
508 mm
Metric Conversion
10 mm = 1 cm
Therefore
508 mm/10 mm/cm=
50.8 cm or
50 cm + 8 mm

Module 9

This picture 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.

Introduce Metric (SI): Common Conversations

COMMON SI WELDING CONVERSIONS

| TO CONVERT FROM	MULTIPLY BY	TO OBTAIN THIS SI TERM
inch (in)	25.4	mm
foot (ft)	305	mm
foot (ft)	0.305	m
inches per min travel (ipm)	0.42	mm/sec
impact (ft-lb)	1.36	Joules
pound (lb)	0.454	kg
ft³/hr (CFH)	0.47	L/min
pressure (psi)	6.9	kPa
strength (psi)	0.0069	MPa
area (ft²)	0.093	m²
volume (in³)	1640	mm³
heat input (J/in)	39.4	J/m

Module 9

Metric: In many ways, the metric system (now **SI** for International System of Units) is simpler than our current US system of measures. It some ways it is just different. Many years ago measurement was crude and inaccurate. The yard was supposed to be half the span from finger-tip to finger-tip of a King's outstretched arms. The pound was the *"weight of 7,000 grains of barley chosen from the middle ear"*. Rough and inaccurate measurement was good enough for barter between friends and relatives but trouble arose when commercial trade began. Relationships evolving out of haphazard methods of measurement were anything but simple. And as merchants adopted a form of measurement that would be met with more acceptance by the general public of that era the outcome resulted in having: 2 pints to the quart, 4 quarts to the gallon, 22 yards to a chain,16 ounces to the pound, 12 inches to a foot, 3 feet in a yard, 5,280 feet in a mile.

SI, the international system of measurement has evolved today was assisted in it's development as a result of for-sighted American Fathers like Thomas Jefferson who gave us an American dollar with 100 cents and Dr. Ben Franklin who, along with other devoted attendees of the Academy of Sciences in Paris contributed significantly to the design and simplicity of measuring in metric dimensions for Americans today.

Metric; Proper Rounding

HOW BIG?

1 inch

1 +/- .001 inches

INTENDED PRECISION
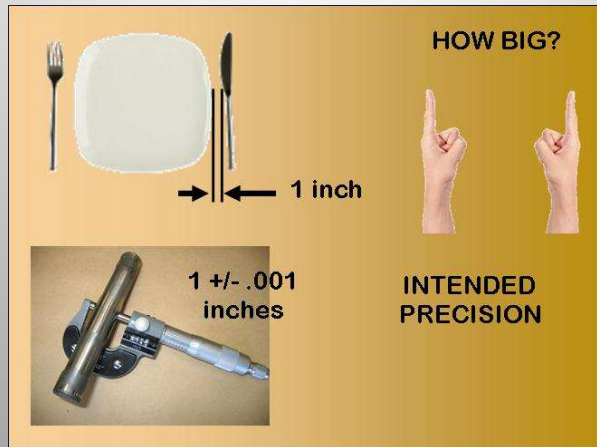
The key to properly rounding unit conversions is understanding what was intended by the original dimension.

The common use of a calculator has made the thought process needed when rounding often bypassed! For example, if someone states a measurement 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 a precise inch! If someone said place it 25 mm from the plate and we used the conversion factor in the previous table that would be 25/25.4 = 0.98425 inches. That is close to 63/64 th. Would we be expected to obtain a steel rule to set the table. Obviously that was not the attention! Be sure you're not including more precision than intended because a calculator provided an answer! Therefore the SI equivalent to placing the knife 1 inch is 25 mm not 25.4 mm. Usually providing the answer in the same number of digits provides the proper answer. It typically assumes the digit after the last significant digit listed is about 1/10 of that value. For a bearing journal, dimensions may be given defining the allowable tolerance, i.e. 1 +/- .001 inches clearly defining the precision intended. That converts to a minimum of 1-.001 = .999 inch minimum. Converting to metric = 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 we use 4 digits that would convert 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 we left all 6 digits from the calculation, the machinist have to use a more precise device to make and measure the shaft than intended!

Introduce Metric (SI): It Started in USA!

- In 1782 Thomas Jefferson suggested the messy currency situation in the US needed to be fixed. We were using British Pounds, Dutch Gilders and Spanish Pieces of Eight! He proposed the base 10 currency system we use today.
- Jefferson and Ben Franklin strongly supported a base 10 measurement system that was being developed in France (now called SI.)
- In 1790 George Washington in his 1st Congressional address said *"Uniformity of currency, weights and measures is of great importance."* Congress only supported currency!
- Napoleon promoted the new measurement system as part of his sweeping government reforms! **Typical of the US Congress they left us with our messy measurement system!**

Module 9

In the late 1700's Ben **Franklin** and Thomas **Jefferson** promoted their strong support for decimal measurement and for decimal currency. Money and measuring methods were a mess, in the USA, currencies in use came from the nations who had an interest in the USA. There were such things as Pounds from the UK, Guilders from the Netherlands, Pieces of Eight and Reals from Spain, and this mess had been recognized by **Thomas Jefferson** as early as 1782, when he suggested the use of a decimal currency for the USA. In 1790 George **Washington** in his first annual message to Congress, reminded the legislators *"Uniformity in the currency, weights, and measures of the United States is an object of great importance, and will, I am persuaded, be duly attended to."* The SI (metric system) was part of the reforms Napoleon introduced as a symbol of the new meritocracy, and it was spread to all the lands under his control; this coherent method of measurement served to fuel the scientific progress of the coming decades.

The USA had a major influence on the measurement leaders in France, who were developing the decimal metric system to become the legal French measuring system.

Dimensional Analysis:

$$80gCu\left(\frac{1molCU}{63.5g}\right)\left(\frac{1molCu_2S}{2molCu}\right)\left(\frac{159.1Cu_2S}{1molCu_2S}\right)=1.00x10^2\,gCu_2S$$

$$\sum P = P1 + P2 + P3..._{...}$$

$$PV = I$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

A unit describes a number. A value is both the number and the unit that describes it, like 175 amps. The 175 means nothing by itself and amps by itself does not define what you'll use when welding.

Module 9

A unit describes a number. These are examples of units: minute, second, pound, inch, square feet (also written as ft^2), amps, volts, cubic inch (also written as in^3) etc. A value is both the number and the unit that describes it, like 175 amps. The 175 means nothing by itself and amps by itself does not define what you'll use when welding.

For example, your asked by purchasing; "Why so much shielding gas is being used every month?" The answer your looking for is dollars spent per month on gas. The units will be $/month. You know your welders are supposed to use 35 cubic feet of gas per hour while welding or 35 CFH. You also know you only use 0.035 inch diameter solid wire. On average the power supplies are all set at 150 amps. You also know that 0.035 inch wire has a burn-off rate of 4.1 pounds of wire melted per hour at a welding current of 150 amps (lbs wire/hr). Purchasing indicates gas costs $10/100 cubic feet and you bought on average of the $5000/month for the past year. You ask how many pounds of wire were purchased last year. Your told it was 80,000 pounds (lbs.) You know you need an answer of $ gas/year. You know you used 80,000 lbs wire/year. If you knew how many hours the welders actually were welding you could figure the amount of shielding gas they should have used.   You do know they used 80,000 lbs wire/yr. You also know that wire melts at 4.1 lbs/hr. What your looking for is how many hours of actual arc time welded. If you divide lbs/yr by lbs/hr the lbs will cancel and your left with hr/year

Dimensional Analysis:
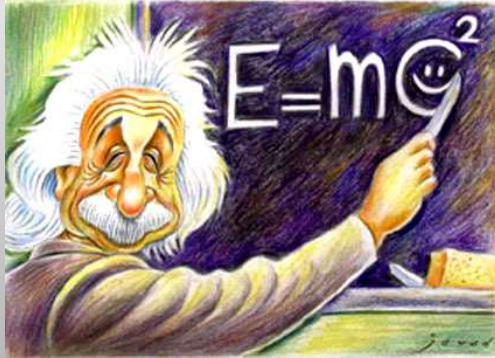
This famous Equation Needs Units:

E (energy; Joules) = m (mass; kg) $*$ C^2 (speed of light²; m²/sec²)

Check a **Joule = kg $*$ (m²/sec²)**

Module 9

The famous Einstein Equation **E=mc²** means nothing without the units! Sometimes they are just understood and left off. However by simply putting the units with the values or even just putting units in without numbers helps define if the proper values are being inserted. For this equation, using SI units: **E, energy, has units of Joules; m, mass is measured in kilograms** and the **speed of light, C** in SI units is measured in **m/sec.** The speed of light is squared in the equation therefore the units are as well, m²/sec²   As a check a joule is defined as a kg*(m²/sec²)

Basic Math Functions, Symbols and Algebra

$$2 + 2 = \frac{(\sqrt[3]{27} + (\sin \Theta)^2 + (\cos \Theta)^2)}{* \int_0^{\frac{\pi}{2}} \cos \Theta \, d\Theta} =$$
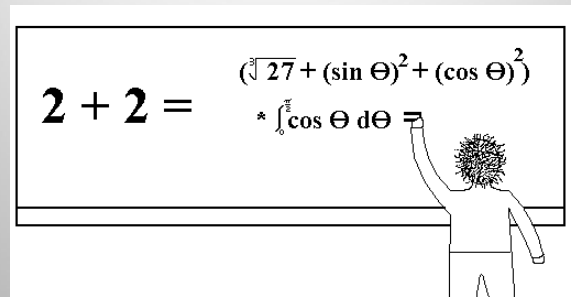
Einstein did not come up with his famous formula E=mc[2] by measuring anything but only through thought-experiments at his desk.
Some of the following material is needed to express an idea into terms that can be used broadly.
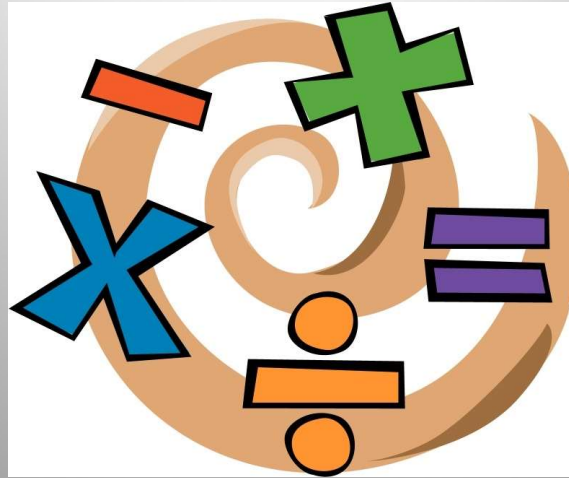
Module 9

I learned from my college Freshman Math Professor, Dr. Mainardi, most text books are written by Professors to impress their piers, NOT for the student! His math book was truly for the student. Professor Mainardi had taught himself French to learn "The Calculus," which was at the time was only written in French! He went on to work at Bell Labs and invented the switching system used for rotary dial phones! When he retired he became a professor at the engineering college I attended. I recall I had struggled with Calculus in high school because it was so abstract. Professor Mainardi's first calculus example was replacing blood in a blue baby. You were to determine how much "good" blood needed to be added as the mixture of good and "bad" blood was removed until 80% was replaced, as I recall. That could only be calculated using calculus. We'll try to make this section as useful. Don't worry we're not going to introduce calculus here! There is no need.

Basic Math Functions & Symbols

Module 9

There are a number of symbols used in math. In this Learning Program, we will use the ones that are employed when using a computer spreadsheet, like Microsoft Excel (see references in Appendix.) It is much easier to use a spreadsheet program to make ongoing calculations than with a simple calculator.

First the basic math functions: **Addition** will use the symbol (+): **Subtraction** will use (-): For **Multiplication** will use (*) : and **Division** will use (/), this allows equations to be presented all on one line, an advantage when typing! Another common symbol used when writing equations are brackets ( ). If they are used, the rule is always to make the operations within the innermost brackets first. We'll use this example where letters replace values in a general equation. Example: (a+b)*c. If we're told a=2.5, b=4 and c=2 we must first add 2.5 + 4 = 6.5. Then we can multiply 6.5 * 2 = 13. We'll see with a few rules in the next slides that we could also have multiplied 2.5 *2 and added it to 4*2 and obtained the same result, i.e. 2.5*2=5 and 4*2=8 and adding them we get 5+8=13; the same result. But in general, always calculate the inner most brackets first.
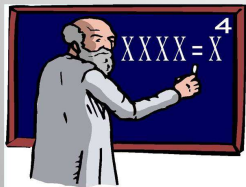
$$\sqrt{x} = x^{\frac{1}{2}} = X^{0.5}$$

$$\sqrt[3]{x} = x^{\frac{1}{3}} = X^{0.333}$$

$XXXX = X^4$

- Exponents are a simplified way to indicate a number is to be multiplied by itself a specific number of time. As in the above example if X is 3 then $X^4 = 3*3*3*3 = 81$
- As apposed to using the square root sign the exponent can be less than 1, for example ½ or 0.5. than what is being said is what number if multiplied by itself will equal X, i.e. if X = 9 what number multiplied by itself = 9? The answer is 3.
- The cubed root is similar. What number multiplied by itself 3 times will equal X? If X is 64 the answer is 4.

Exponents are a simplified way to indicate a number is to be multiplied by itself a specific number of time. We will use the exponent designation in this program which is a deviation from a spreadsheet program where, for example X2 would be written X^2. And a square root would be written 9^0.5. Note in general we will use a 0 in front of a decimal (.) so it is easier to readily see a number like 0.5 is less than 1 versus just writing .5 which is the same valve but could be confused with 5.

Repeating the above example if X is 3 then $X^4 = 3*3*3*3 = 81$.   Or in a spreadsheet it would be written 3^4. In the second example above, what number multiplied by itself = 9? The answer is 3.   Or written is a spreadsheet =9^0.5. The cubed root asks what number multiplied by itself 3 times will equal X? If X is 64 the answer is 4. Or as a spreadsheet entry =64^0.333 Note caring 1/3 to 3 places is usually sufficient for engineering calculation even though it could be extended to an infinite number of 3's!

One last item negative exponents. X^{-1} for example = 1/X; X^{-2} = $1/X^2$

Basic Math: Basic Algebra

With Algebra, numbers are replaced with symbols. They can represent different values as the problem changes. For example change the amperage and the weld heat input changes. The equation remains Volts * Amps/ Travel Speed

Module 9

Basic algebra introduces the concept of variables of representing numbers Statements based on these variables are manipulated using the rules of operations that apply to numbers, such as addition. This can be done for a variety of reasons, including equation solving. There are several rules that must be followed when manipulating these variables. We'll cover a few that may be used. Advanced algebra deals with more complex rules we will not need.

Rule #1 – Product Rule: $x^m * x^n = x^{(m+n)}$

Rule #2 – Power Rule: $(x^m)^n = x^{(m*n)}$

Rule #3 – Product Rule-2 Bases: $x^m*y^n = x^m*y^n$

Rule #4 – Power Rule-2 Bases: $(x^m*y^n)^z = x^{(m*z)}*y^{(n*z)}$

$(x^m/y^n)^z = x^{(m*z)}/y^{(n*z)}$

Rule #5 – Negative Rule: $x^{-m} = 1/(x^m)$

Rule #6 – Quotient Rule: $x^m/x^n = x^{(m-n)}$

Rule #7 – Distributive Rule:

Exponents Distribute across multiplication and division

Exponents <u>DO NOT</u> Distribute across addition and subtraction

Basic algebra introduces the concept of variables of representing numbers. Statements based on these variables are manipulated using the rules of operations that apply to numbers, such as addition. This can be done for a variety of reasons, including equation solving. There are several rules that must be followed when manipulating these variables. We'll cover a few that may be used.

Looking at the above table and starting with Rule 7: here is:

WHAT YOU CANNOT DO - $X^2+X^3 = ?$ You can not combine with addition.

WHAT YOU CAN DO - $X^2 * X^3 = X^5$ You can combine if the variables are operated on by multiplication or division .i.e. in this case of multiplication the exponents are added.

The other rules are mostly obvious so you can combine or distribute as they define. The only somewhat different rule is # 5, the Negative Rule. Therefore $X^{-2} = 1/X^2$

The other thing to remember is you can always multiple a function by one and not change it's value. $x/x=1$ so it can be multiplied by one side and not change the value. You can also multiple (or divide) both sides of an equation by the same value and not change the original value. With these two and those above we can solve complex equations for the value of X. For example given: $a*X^2 = b/X$ multiple both sides by X, then: $X*a*X^2 = X*(b/X)$ Then using the Product rule $a*X^3 = b$;   Divide both sides by a : $(a*X^3)/a = b/a$ or since $a/a=1$ $X^3 = b/a$ Then raise both sides to the 1/3 power $= (X^3)^{0.333} = (b/a)^{0.333}$ or $X= (b/a)^{0.333}$

References

1. *AWS Welding Handbook, Volume 1, 9th Addition; pp 7*
2. *"The Science of Arc Welding" by C. E. Jackson. Linde Publication # 52-201 (printed 1968) Also available* "The Science of Arc Welding," by C. E. Jackson; The Welding Journal, (39) (Three Parts) 129-s to 140-s;177-s to 190-s; and 225-s to 230-s
3. Wilkinson, M. E., Direct Gas Shield Analysis to Determine Shielding Efficiency. Report of The Welding Institute, Cambridge, England, December 1974
4. Lyttle, K. and Stapon, G., Simplifying Shielding Gas Selection. Practical Welding Today, Vol. 9, No. 1, Jan/Feb 2005.
5. Adams, C. M. Jr, 1958, Cooling rates and peak temperatures in fusion welding. Welding Journal 37(15):
6. R. A. Grange and Kiefer; "Transformation of Austenite on Continuous Cooling and Relation to Transformation at Constant Temperature." Transactions of the American Society of Metals; Vol. 29 1941
7. Weber, R., How to Save 20% on Welding Costs. Trailer/Body Builders, Vol 44, Number 3, January 2003
8. Standifer, L. R., Shielding Gas Consumption Efficiency. The Fabricator, Volume 30, Number 6, June 2000.

Module 9

Additional reading and video's to consider:

"Advanced Automotive Welding" by Jerry Uttrachi; 176 page book available at http://netwelding.com/prod02.htm

American Welding Society Publications: available at http://pubs.aws.org/

1. Welding Handbook Series (Comprehensive multivolume set-Expensive)
2. Pocket Handbook Series (Low cost on specific subjects)
3. WHC1.04 - WELDING METALLURGY (low cost, recommended)
4. PRGWM PRACTICE REFERENCE GUIDE TO WELDING METALLURGY: KEY CONCEPT FOR WELDABILITY (Moderate Price)
5. WM1.4:1994 FUNDAMENTALS WELDING METALLURGY - VOL.1 (comprehensive)

Free video's related to welding math and use of an Excel Spreadsheet:

1. Welding Math Part 1: http://www.youtube.com/watch?v=CyRwiI-aIZY
2. Welding Math Part 2: http://www.youtube.com/watch?v=1GmGdS7V24g
3. Welding Math Deposition and Penetration: http://www.youtube.com/watch?v=O8zz-Nb0q9Y
4. Welding Math Deposition and Penetration Spreadsheet: http://www.youtube.com/watch?v=cuAbV3FHwQw

W A Technology

Overview of Patented Gas Saver System (GSS™)

The **GSS** is a Patented Gas Delivery Hose Incorporating a Start Flow Surge Limiter That Can Save 50% or More of MIG Shielding Gas Use and Improve Weld Start Quality.

The Problem

The Problem – An orifice or a needle valve are used to set and control gas flow. With Regulator/ Flowmeters (photo right) outlet pressures range from 25 to 80 psi. Flowmeters used on pipelines allow pipeline pressure to exit the flow control valve when welding stops. A typical pipeline pressure is 50 psi.

Flowgauge/Regulators (photo left) operate by setting a pressure above a critical orifice. For most MIG shielding gas flow rates, the pressure exiting the control orifice when welding stops will range from 40 to 70 psi.

However, the pressure needed at the feeder to set the desired flow can range 3 to 8 psi depending on gun length and restrictions that occur when welding, such as spatter in the gas diffuser ports, clogged conduits that also serve as the gas passage in the gun cable. When welding stops, gas fills to regulator or pipeline psi. Therefore, the pressure can be 80/3 = *26* times the pressure needed to flow the desired amount of gas!

Excess Pressure Means Excess Shielding Gas is stored in the gas delivery hose. Most of this excess gas is wasted every time the MIG gun switch is energized, even when just inching the wire. The excess can exceed the amount of gas used while welding!

The Solution

The Solution - Our patented *Gas Saver System* (**GSS**) stores 80%+ less gas when welding stops.

The **GSS** solves this excess stored gas problem by utilizing a custom extruded, very heavy wall, gas delivery hose with much less volume than conventional hoses and uses a surge flow-limiting orifice. Excess stored gas creates another problem as it exits the gun nozzle with a high surge flow at the weld start. Start gas flow rates far exceed the level that allows smooth Laminar flow. It creates turbulent flow that pulls air into the shielding gas stream.
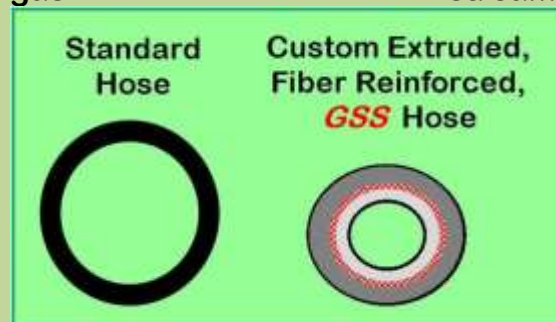

The surge flow restrictor not only adds to waste reduction, it improves weld starts. The start surge flow restrictor is sized so it *does not* limit normal gas flow settings. Welders often see this starting benefit as reduced spatter.

Superior Start Quality -
Limiting start flow velocity to a rate that avoids excessive turbulence is achieved while quickly providing enough extra gas to purge the gun nozzle and weld start area. This controlled surge flow rate eliminates moisture-laden air from being mixed into the gas shield that results in excess spatter and possibly weld porosity.

The patented *GSS* design maintains system pressure to retain *Automatic Flow Compensation* built into standard gas delivery systems since the introduction of MIG and TIG processes! If the pressure is lower than 25 psi, this feature is lost!

Savings Proof:
" A manufacturer making truck boxes reported the following test results. They used their standard gas delivery hose and welded 236 truck box doors with one cylinder of shielding gas. With the *GSS* installed; the same welding conditions and flow rate while welding, they welded 632 of these doors with one cylinder! That is a 63% savings in gas use.
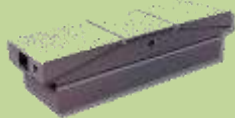
Bottom Line -
The patented *GSS* has no moving parts to wear, maintain or knobs to adjust. It *does not* set the shielding gas flow rate while welding. The welder sets that steady state flow rate, typically with whatever device is being used or any quality flow control. Welders appreciate the start benefits and are not irritated by restrictors that set flow they cannot adjust or low-pressure devices that cause flow variations while welding!

The *GSS* is inexpensive with *Payback* measured in months. Well over 15,000 are in use, collectively saving millions of dollars of shielding gas per year and improving weld start quality.

Welders LOVE The Improved Starts

EASY TO INSTALL
Just Replace Your Gas Delivery Hose with Our GSS
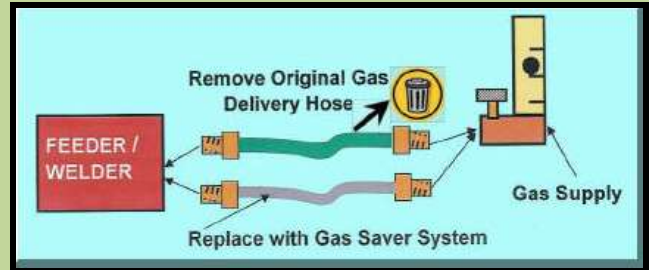
Welders Setting Excess Flow?

We have another patented product that can be used in conjunction with our *GSS*. Our Flow Rate Limiter and Lock (*FRLL*.)

This billet aluminum part fits over the flow control adjustment knob on most flowmeters. A set screw locks the *FRLL* on the knob so it cannot be turned higher than where it is set. A small brass lock blocks access to the set screw! A number of customers use both, like a motorcycle manufacturer and Tier 1 automotive exhaust supplier.

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US Patent Number 6,610,957
*These patents cover some of our other patented products;
7,019,248; 8,336,113*

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