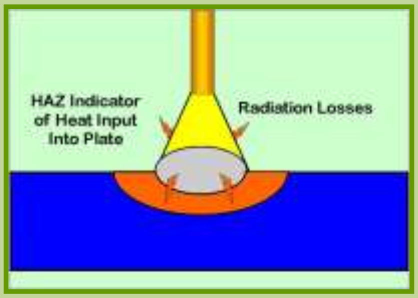
WA Technology

Effective Welding Heat Input

ISSUES MEASURING HEAT INPUT

Many weldment properties are dependent on welding heat input. This is especially true for quenched and tempered (Q&T) steels where optimum strength and impact properties are achieved by quenching the plate and tempering back to provide a high strength, tough material.



When Q&T steels are welded the area adjacent to the weld deposit is heated almost to the melting point of steel. Mechanical properties are particularly changed and mostly degraded to a temperature of about 1300 degrees F. These structural changes in the material are sufficient that a chemical etch will alter the appearance of this zone from almost melting to about 1300 degrees F. This is called the Heat Affected Zone or HAZ. The line that demarks the plate that reached the 1300 degree F point is referred to as the outer etching boundary.

Visible in the photo of this HY-80 submerged arc weld cross section are the: 1) weld nugget, 2) fusion line which was at the melting temperature of steel and 3) the outer etching boundary line in the base plate that reached ~1300 degrees F. With the etchant used it is at the outer edge of the light area.

CODE REQUIREMENTS

Codes for welding Q&T steels often specify the maximum allowable "Heat Input." Heat input is usually defined using a simple formula of (Volts x Amps)/Travel Speed in ipm times a unit conversion of 60 to provide joules/inch. For thicker sections (greater than ~ ¾ inches) the maximum allowable heat input is often specified as 60,000 joules per inch of 60 kj/inch.

ISSUES RELATED TO HEAT INPUT CALCULATIONS

None of the more complex issues such as arc efficiency, the amount of heat that is radiated away from the weldment are considered with the simple (Volts x Amps)/ Travel approach. In addition issues arise about how to measure short circuiting MIG or pulsed MIG amps and volts. With these processes there are wide swings in both parameters at frequencies of 200 cycles per second or more.

There are also issues about how to treat the space between multiwire processes such as submerged arc, tandem MIG and Hybrid Laser processes.

PAST RESOLUTION OF CALCULATION ISSUES

Questions about calculating heat input are not new. Two specific efforts (the results of which were not published) are presented here and define a practical way to handle these issues.

Plasma Hot Wire

The first example is one that was tackled over 35 years ago. A newly developed process was to be used to surface HY-80 with Inconel for a Navy vessel. The maximum allowable heat input specified by the Navy was 60 kj/inch. This heat input level was being successfully used with submerged arc welding using 500 amps, 30 volts at 15 ipm travel. However submerged arc welding is about 90% efficient. Meaning 90% of the energy used is conducted to the base material when it can affect the weld and HAZ.

The plasma welding process is only about 50% efficient and the weld bead was to be oscillated. How do we conceder these parameters in the Heat Input calculation? Professor Mel Adams was a consultant to our Welding R&D Laboratory. He gave lecturers on heat transfer in welding as well as other topics. With his help we developed an answer.

Professor Adams had defined that it was not necessary to know actual heat input to define the resulting cooling rate in the base plate which is why maximum heat input levels were specified. What was needed was to define two isotherms and the distance between them to define the cooling rate. In essence 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 had the same cooling rate!

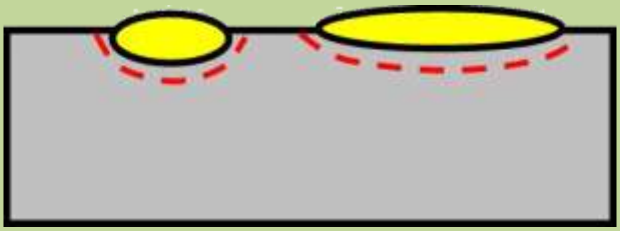
A bead-on-plate weld deposit was made with submerged arc at 60 kj/inch; i.e. 500 amps, 30 volts at 15 ipm. The average width of the HAZ was measured and

the Plasma Hot Wire process parameters adjusted to provide quality deposits and produce the same HAZ width. Deposits were made with various width 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. The equations for peak temperature and references to Professor Adams published papers on the subject are presented in the Appendix.

MultiWire Sub Arc and Oscillated MIG

Several years later 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 multiwre submerged arc.



Electric Boat supplied the plate and made welds with several oscillation widths using MIG welding. They hoped to gain some allowable linear speed reduction as oscillation width increased. We made welds with one, two and three wire submerged arc with the wires in tandem. We selected welding speeds for equal weld heat input using the Volts X Amps /Travel approach assuming all power was in one electrode, i.e. the amps x volts for each wire were added.

We sent the welds to Letourneau University where welding students carefully measured heat affected zone width and also the HAZ area.

Summarizing these tests; 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 all HAZ widths were essentially the same supporting that there is no significant reduction in Effective Heat Input for the spaced electrodes. (Note: the spacings involved where those commonly employed for multiwire submerged arc welding, i.e. 3/4 to 1 ¼ inches.) So again the linear travel speed controls the "Effective Heat Input." Considering the molten puddle length for the three wire system was about 6 inches long this was no surprise!

Bottom Line

The standard simplified equation for defining heat input of:

(Volts x Amps)/Travel Speed

is an effective measure. However it does not consider that some welding processes such as Plasma Welding and TIG Welding have much lower efficiency than say Submerged Arc Welding. It also makes proper measurement of arc power for processes such as Pulsed MIG and Short Circuiting MIG become very important.

However rather than try to define exact arc efficiency with calorimetric methods (whose results are shown to be dependent on arc length, current, travel speed etc) or worry about how a volt and amp meter on a Pulsed MIG power supply integrates instantaneous volts and amps to get accurate power delivery (which they do not) the method defined by Adams is preferred.

If for example 60 kj/inch are allowed it is suggested that a simple bead-on-plate weld deposit be made on the plate material in question with MIG or Submerged Arc. Measure the average heat affected zone width from fusion line to outer etching boundary and define that as the maximum allowed with other processes or process variations.

Paraphrasing Professor Adams Conclusions: *"Equations were developed that are considered particularly accurate for calculating temperatures between two known reference locations such as the fusion boundary and the characteristic etching boundary; in this circumstance there is no need to know knowledge of the arc energy is required."*

"Characteristic etching boundaries in H-80 and T-1 steels are associated with specific peak temperatures regardless of cooling rate, preheat, arc energy or geometry."

VOLTS AND AMPS MEASUREMENTS MUST BE ACCURURATE

The subject of measuring volts and amps in the welding industry has been one that I have found lacking since my early days in welding research! The situation is becoming no better with digital meters, in fact is some instances it may be worse! Significant variations in measurement can easily be made by just moving the meter leads closer or further from the power cables!

Some of the problems and a few solutions are discussed in the Appendix.

APPENDIX

MEASURING EFFECTIVE HEAT INPUT:

Professor Adams proved his rigorous theory related to "Effective Heat Input" in several technical papers published in the Welding Journal:

1. C. M. Adams Jr.; "Cooling Rates and Peak Temperatures in Fusion Welding;"; The Welding Journal; May 1958
2. C.M. Jr. Adams, J.M. Barry, Zvi Paley; "Heat Conduction from Moving Arcs in Welding;" The Welding Journal; March 1963
3. C.M. Jr. Adams, J.M. Barry, Zvi Paley; "Heat Flow in Welding Heavy Steel Plate;" The Welding Journal; February 1964

The following equation for the temperatures developed in a weldment HAZ is presented in reference 1 above:

$$1 / (T_p - T_o) = (17.1 * d * C * h * Y)^{0.5} / H_{net} + 1 / (T_m - T_o)$$

Where:

Tp = Peak or Max temperature; ^oF

To = Initial plate temperature; ^oF
d =Density; lb / in3

C = Specific Heat; BTU/ lb ^oF
h = Plate thickness; inch
Y = Distance from weld fusion line; inch

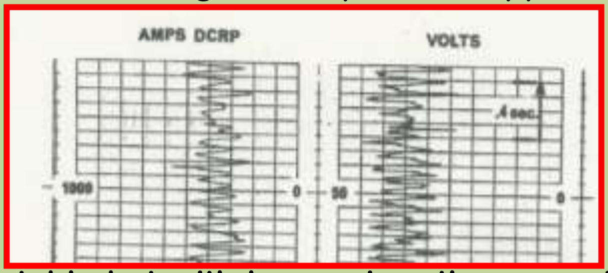
H_{net} = Net heat input/ unit length; ……….BTU/inch

Tm = Melting Point of Material; ^oF

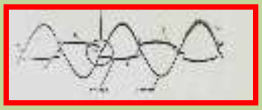
MEASUING VOLTS AND AMPS

Since my welding R&D work in the mid 1960's measuring these critical process variables was always a concern. We used Esterline-Angus strip recording instruments on all our welders. While making a Consumable Guide Electroslag weld in a heavy steel plate there was plenty of time to rearrange the cables including the voltage pick-up leads. In doing so I noticed as I moved the voltage pick-up leads the voltage reading changed! In fact it was easy to change the reading by putting the voltage pick-up closer or further away from the power cables! And that was with a very stable process like Electroslag!

The submerged arc process appears



stable but with large wires the current densities are very low and drop frequency low as well, sometimes 4 or 5 drops per second. As these drops are formed and leave the electrode the arc length increases considerably. The arc voltage must change as well. I often used an oscilloscope to "see" what was happening under the flux. The figure above is a trace made using a moderately fast Oscillograph. The weld was made with Constant Current power, a 5/32 inch diameter electrode at relatively low current. The variations in arc voltage and current are obvious. These won't be seen on a conventional volt or amp meter. In fact some sub arc equipment manufacturers use purposely damped meters. These spikes in current can induce even more false readings on volt and amp meter leads!



Other issues arrise with the measurement of AC voltage. Most AC volt meters are calibrated to read the RMS value of a sine wave. In submerged arc the amperage follows essentially a sine wave but the voltage is basically a modified square wave regardless of the type of power supply. Then what is the meter displaying? It depends, is it a D'Arsonval meter movement or Iron Vane!? Or with digital meters all bets are off since the welding equipment or meter manufacturer processes the digital signal and can average over any time they would like! They can also treat other than pure DC or sine wave AC anyway they would like! And in welding, accept for TIG we have few processes that have simple wave forms!

What Can Be Done To Improve Meter Reading Accuracy?

First be sure the volt meter and amperage leads (particularly on DC where low level signal shuts are often used) are not causing false readings. Several techniques can be used such as employing a twisted pair of leads for both power and ground so external fields will cancel.

However another approach is needed when you have power cables 50 feet long going down a boom that can't be twisted with the ground cable! Also when cable is festooned as shown in the upper left photo.

One successful technique I have used is to change the "high impedance" circuit measurement folks are so eager to use with a low impedance approach. "High impedance" referees to the measurement device not interfering with the circuit. A basic principle of measurement. However in welding we have so much current available - who cares! Therefore put a resistor across the voltmeter and draw some current. This avoids the magnetic fields on power or ground cables from inducing power that can alter the signal! Depending on the meter location you may need to use larger size meter wires and may have to put a low ohm high wattage resistor outside the control box. AC amperage meters are usually more accurate since they often employ a transformer and measure significant amperage (5 amps for example) at full scale. DC amps using millivolt shunts are more of a problem but the twisted lead approach can usually be employed for amp meters.

Often the most important thing to have is consistent readings. In one case a shipyard was having trouble with an inspector who wanted the meters on the power source to match those on the welder control panel. The best approach? Eliminate the meters on the power source and use only one set!

Bottom Line:

It can only be suggested that there is a need to recognize what causes variations in meter readings and when checking meter accuracy be sure you're using the same meter brand and model. Check to be sure the meter leads are not being affected by their proximity to the power cables.

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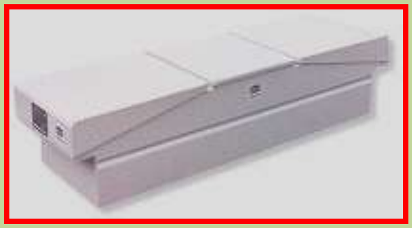

Tests were conducted using cylinder gas. With their standard gas delivery hose they welded **236** doors, a high volume part, with one gas cylinder. Then they installed our ***GSS*** and with no other changes welded **632** doors with one cylinder! *They ordered 25 for all their MIG welders.*

Stated another way; to weld ***632*** doors with their old gas delivery hose they would have used ***2.7*** cylinders of shielding gas versus the ***1*** with the ***GSS !***

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

Number of Cylinders Needed With Standard Gas Delivery Hose

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

The amount of shielding gas waste and therefore the savings potential depends on a number of factors. The gas surge at the weld start is caused by a pressure build-up in the gas delivery hose when welding stops. The length of shielding gas delivery hose is a significant factor in determining the amount of gas waste as is the number of starts and stops. The pressure in the gas delivery system is also a factor; however a minimum of 25 psi is needed to maintain the Automatic Flow Compensation built into gas delivery systems since the introduction on MIG welding. Pipeline pressure in bulk gas installations is often 50 psi producing an even higher gas waste.

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

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

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

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

Are Your Welders Setting Excessive Flow Rates? See Our Patented *Flow Rate Limiter And Lock* - Photo Right.

The ***GSS*** is covered by US Patent Number 6,610,957
Other products covered by US Patents 7,015,412; 7,019,248 and 7,462,799