Date: December 15, 2006

To: Mr. Tom Schlafly
AISC, One East Wacker Drive, Suite 3100
Chicago, IL 60601-2001
312-670-5412

Subject: FINAL REPORT: Studs Thru Deck Welding, Coated Steels

Dear Tom,

Please find enclosed the Final Report for the work performed between March 1-November 30, 2006. The most important ideas conveyed in this report include:

❖ An automated stud welding control and data acquisition was built to improve testing consistency. Nonetheless, through-deck welding on coated steels remains less consistent that welding on bare steels, while the weld quality deteriorated with increased Zn content in the coatings.

❖ A new external electromagnet coil retrofitted to the stud gun eliminated arc blow, when using traditional power supplies. The problems of extra weight, need for separate power supply and high temperature wear remain to be resolved in the future.

❖ The arc blow problem was also successfully solved using pulsed waveform control. This solution applies only to new, inverter-based power supplies.

❖ The arc initiation problem for all coating types was solved by using a modified ferrule/steel wool combination. Nevertheless, Zn-bearing coatings were still more detrimental to the weld quality than insulating paints.

The principles of improving through deck stud welding on coated steels have been successfully developed. Commercial implementation of a prototype remains to be performed, with careful consideration of safety practices for weld fume control

In case you have any questions, please call at 903-233-3918.

Thank you and regards,

Yoni Adonyi Ph.D., P.E.

EXECUTIVE SUMMARY

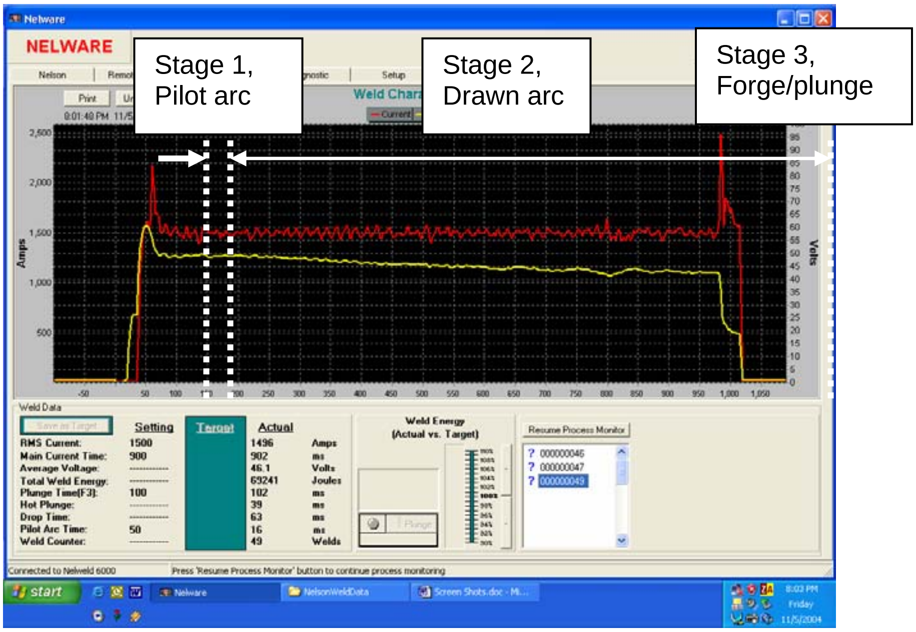
This research studied methods of improving the consistency and quality of through-deck stud welds onto various coated steels to improve the acceptance rates in construction applications. A specialized fixture and automated data acquisition/control system were built using National Instrument's LabVIEW software. A design of experiments was performed to investigate importance and interactions of welding parameters such as weld time, weld current, lift distance, plunge depth, and plunge dampening rate.

Without modifying the current welding technology, stud welding to insulating alkyd-based coatings was more consistent than welding onto Zn powder paints or HDG. Changes needed to improve weld consistency for all coating were: 1) use of an external arc stabilizing solenoid (for a traditional transformer-rectifier) and 2) waveform control (for a new inverter-based power supply). While both were viable methods of improving the consistency of through-deck stud welds, we recommend the solution based on the new power supply.

1.0 BACKGROUND

Past work on stud welding in the steel building industry is regulated by AISC specification (Ref. 1), which has successfully been used for many years. In construction of large, steel-concrete composite structures, stud weld are commonly used to strengthen the structure by acting as shear connectors between the concrete slab and the structural steel girders. In this application, a galvanized decking is placed on top of the steel girder as part of the concrete form, and it is general practice to weld through the galvanized decking to the base metal of the steel girder. On bare, uncoated steels, this practice is viable and reliable means of welding studs. The problem arises with the move to start using coated steels in these concrete structures. It is desirable to use coated steels to increase the life of the structure.

Welding through a galvanized corrugated steel sheet deck has been a special application of stud welding (Ref. 2), where a 16-to 20-gauge steel sheet coated with Zn has to be fused between the stud and the beam, a.k.a. through-deck welding. This corrugated deck is later filled with concrete, forming a "composite" structure for parking garages and other buildings. Such a typical welding cycle is illustrated in Figure 1.



Weld Data

	Setting	Target	Actual	
RMS Current:	1500		1496	Amps
Main Current Time:	900		902	ms
Average Voltage:	----------		46.1	Volts
Total Weld Energy:	----------		69241	Joules
Plunge Time(F3):	100		102	ms
Hot Plunge:	----------		39	ms
Drop Time:	----------		63	ms
Pilot Arc Time:	50		16	ms
Weld Counter:	----------		49	Welds

Weld Energy
(Actual vs. Target)

? 000000046
? 000000047
? 000000049

Connected to Nelweld 6000

Press 'Resume Process Monitor' button to continue process monitoring

Figure 1. Typical data acquired using the Nelweld 6000 D/A system. Red shows current, white shows arc voltage variations within the 900 msec needed to complete a weld.

Preliminary experiments focused on stud welding parameter optimization. One major observation made during this stage of welding was the presence of asymmetric welds which most likely caused by DC arc blow. When the secondary ground cables were wound around the arc to cause a more symmetrical external electromagnetic field, the arc blow was eliminated. Hence, a brief discussion on the origins of arc blow in fusion welding follows.

Arc blow is a common phenomenon in DC arc welding that occurs when asymmetrical magnetic fields exert a non-uniform force on the welding arc which pushes the arc off to one side. When this configuration occurs, heating and metal transfer across the arc become non-uniform and incomplete fusion occurs across the nominal cross-section of the weld. These asymmetrical fields are also produced in the stud welding process when the current running in a vertical direction through the electrode is forced to change direction. When this occurs, the self-induced magnetic field produced by the current is forced to increase in intensity on the inside corner of the turn while simultaneously being spread thin on the outside of the turn.

It is this difference of magnetic field density on opposing sides of the arc that produces the force differential leading to the undesirable condition of arc blow. The principles of arc blow have been discussed in a previous progress report (Ref. 1).

Figure 2. Typical arc blow causing incomplete fusion at the stud/base metal interface. This condition can readily be reproduced by using asymmetrical ground return setup.

The second problem with through-deck stud welding on coated steels was associated with arc instability due to the presence of Zinc from those coatings containing particles of Zn for improved cathodic protection or from the HDG coating. Indeed, in many arc- and power beam welding processes such as Gas Metal Arc Welding and Laser Beam Welding, the vaporized Zn has been often found entrapped as porosity in the weld (Ref. 2-4). It was no different in the present project, where Zn-coated pores were often associated with failed welds, Figure 3.

Figure 3. Typical lack of fusion type discontinuity caused by entrapped Zn

Finally, an optimum stud weld targeted in this study is shown in Figure 4. Notice the full and uniform “flash” around the circumference. If destructively tested in tension or bending, this weld will most likely fail in the shank.

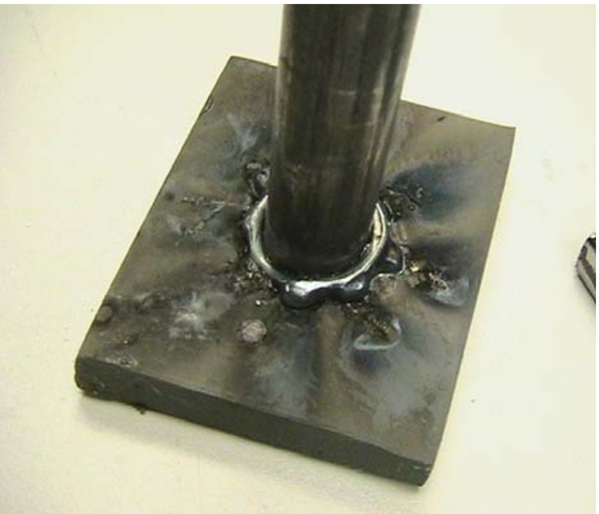


Figure 4. Optimum weld showing full flash and stable parameters (target)

2.0 OBJECTIVES

The experimental research was aimed at understanding the fundamentals of drawn-arc stud welding and propose new concepts for improved weld quality on coated steels. The two focus areas addressed were 1) arc instability due to Zn in coatings and 2) arc blow due to asymmetric magnetic fields induced during DC welding.

3.0 METHODOLOGY

The following types of equipment, materials and parameters were used:

3.1 Equipment

Because stud welding is essentially a semi-automatic process, several variables can have a very important effect on the weld quality. Stud gun position relative to the base metal, pressure applied by the operator, ground cable position, accuracy in stud lift, spring loading wear, etc. are some of the most important process variables. A few automated fixture were built for improving the consistency of welding. The latest model LabView software was installed to activate and acquire data from the process.

The fixture was built to hold the stud welding gun to eliminate the variability added by an operator. The gun was clamped into the fixture use U-clamps, and is on an arm that pivots so the gun is always in the same position. Specimens are clamped into a vice that is welded to the table to ensure proper grounding. The system for monitoring the vertical displacement of the stud is mounted to the pivoting arm of the fixture.

The box containing the workings of the vertical displacement sensor also acts as a junction box for the voltage monitoring wires. In this way, multiple cables are eliminated having only one coming from this single box. Several improvements were made to the welding fixture, see Figures 5a-5d.

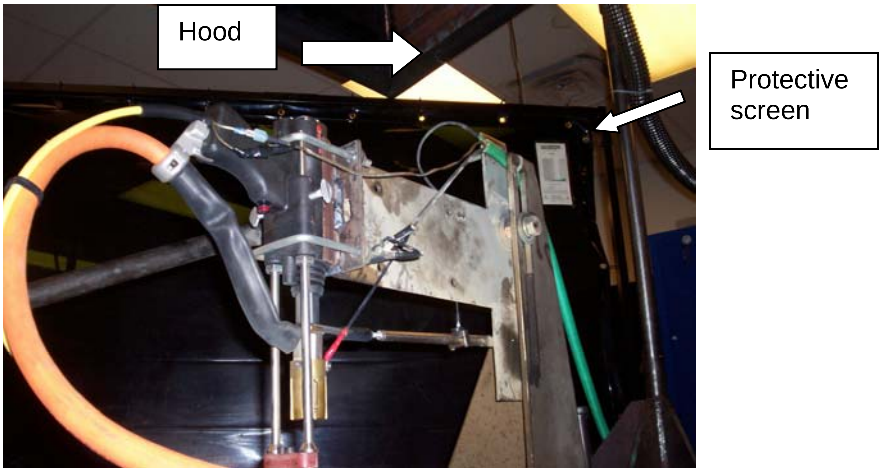


Figure 5a. Final version of the automated welding setup, showing safety devices: fume exhaust hood and arc radiation shielding screen.

The importance of proper grounding connection can not be emphasized enough, especially when decking material (sheet) is inserted between the stud and the coated steel (Figure 5b)

Figure 5b. Setup, latest version. Note the symmetrically grounded vice holding the specimen

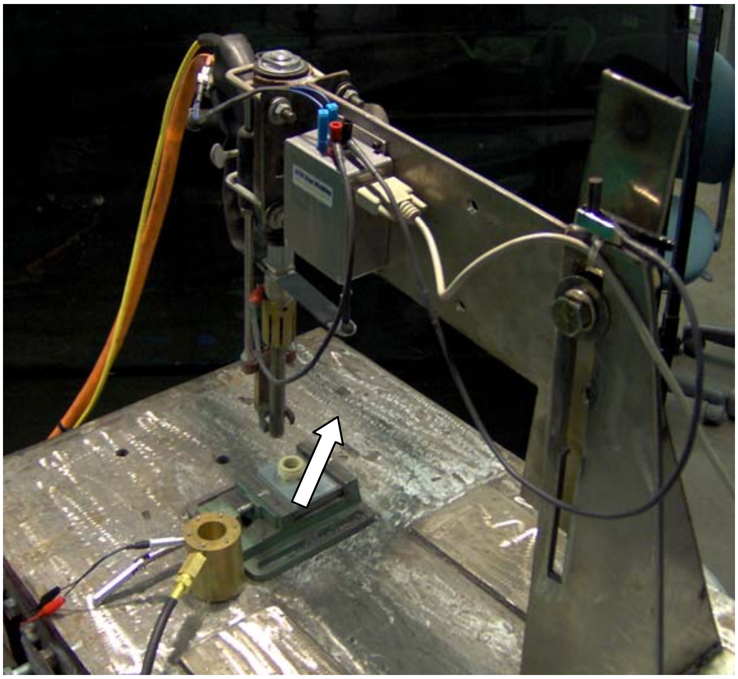


Fig. 5c – Stud welding fixture, fabricated to eliminate operator-induced, uncontrollable variables. Note the separate ACS coil, later to replace the centering device on the gun (arrow)

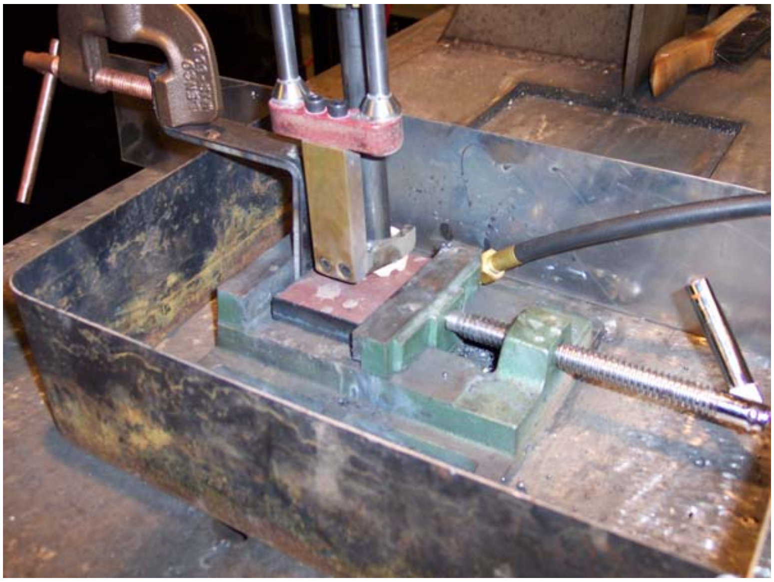
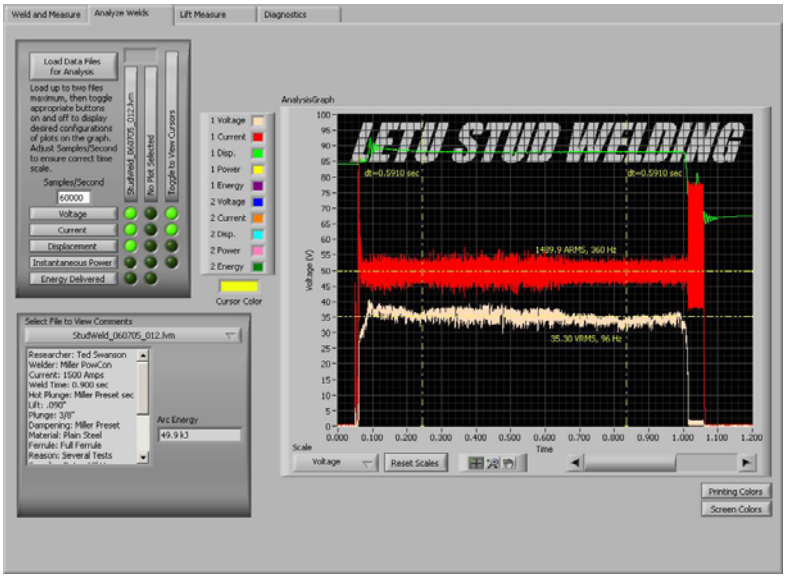


Figure 5d. Asymmetrical ground return setup used to intentionally induce arc blow

A new data acquisition (DAQ) was set up to evaluate the waveform of the Nelson Nelweld 6000 and the PowCon 875. This was needed to observe waveform characteristics by sampling at frequencies greater than two times that of the highest frequency used. The DAQ system used is a National Instruments SCXI-1000 which collects voltage signals at a maximum rate of 200 KHz. The SCXI digitizes the signal and sends the data to the computer via USB. A LabVIEW software program receives the data and writes a file. The LabVIEW program was also used to read the file for analysis. The DAQ system was compared to the Nelweld 6000 as a benchmark to verify its accuracy

At very high acquisition rates of 64,000 data/second, the three most important welding parameters recorded (current, voltage and axial displacement) can well identify process instabilities – see Figures 6a and 6b.



Load up to two files maximum, then toggle appropriate buttons on and off to display desired configurations of plots on the graph. Adjust Samples/Second to ensure correct time scale.

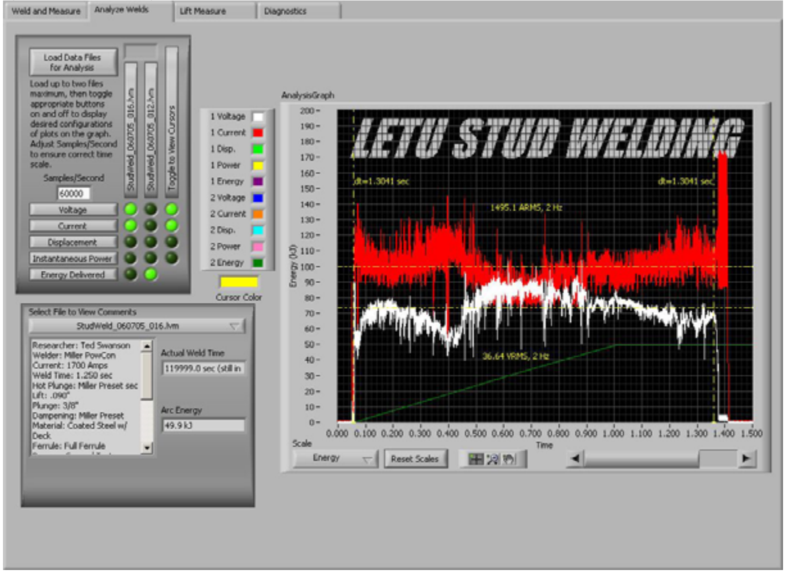
Samples/Second: 60000

Select File to View Comments: StudWeld_060705_012.lvm

Researcher: Ted Swanson
Welder: Miller PowCon
Current: 1500 Amps
Weld Time: 0.900 sec
Hot Plunge: Miller Preset sec
Lift: .090"
Plunge: 3/8"
Dampening: Miller Preset
Material: Plain Steel
Ferrule: Full Ferrule
Reason: Several Tests

Arc Energy: 49.9 kJ

Figure 6a. Typical data acquired during stud welding bare steel (reference)



Load up to two files maximum, then toggle appropriate buttons on and off to display desired configurations of plots on the graph. Adjust Samples/Second to ensure correct time scale.

Samples/Second: 60000

Select File to View Comments: StudWeld_060705_016.lvm

Researcher: Ted Swanson
Welder: Miller PowCon
Current: 1700 Amps
Weld Time: 1.250 sec
Hot Plunge: Miller Preset sec
Lift: .090"
Plunge: 3/8"
Dampening: Miller Preset
Material: Coated Steel w/ Deck
Ferrule: Full Ferrule

Actual Weld Time: 119999.0 sec (still in

Arc Energy: 49.9 kJ

Figure 6b. Typical current (red) and voltage (white) instability during welding on coated steels

A device for monitoring the stud axial position during welding was also used to verify stud position relative to current and voltage. The DVRT has a signal conditioning box which sends the analog voltage signal to the DAQ via a coaxial cable. The DVRT does not have sufficient range of motion to be attached directly to the stud gun. A lever was used to give a 3:1 ratio on the stud position. This allowed a useable stroke of approximately 1” for the stud gun. Typical displacement output is shown in Figure 7.

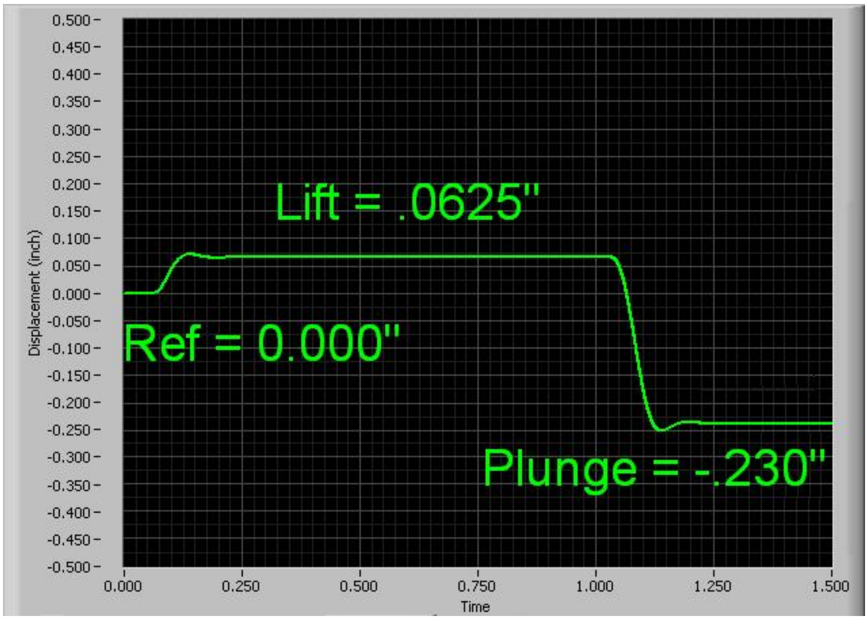


Figure 7. Typical axial motion data for a stud during welding. Positive numbers indicate upward, negative the downward motion

3.2 Materials

The 3/4” diameter stud, bare and coated base metals and the 16 gauge galvanized sheet decking are shown in Figure 8

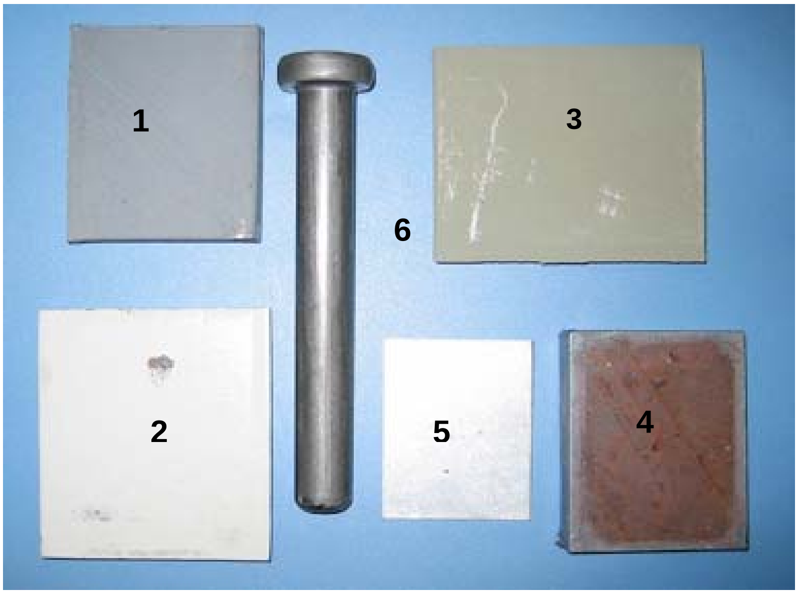


Figure 8 – Materials used. Shown are :

1) Nucor (Vulcraft) coating,

2) Hot-dipped galvanized HDG,

3) Carbozinc,

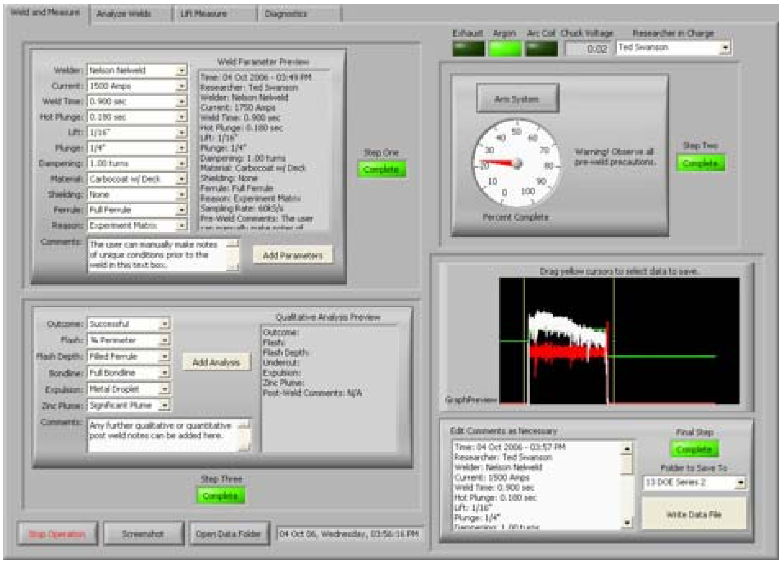
4) Bare steel,

5) Galvanized decking, and

6) A Nelson ¾” stud.

3.3 Welding Methodology

To perform a stud weld in this study, the following procedure was followed. First, desired parameters, such as lift, plunge, weld time, weld current, and dampening, are adjusted as needed. Next, a stud is inserted into the stud welding gun that is mounted in the fixture, which is then lowered into place onto the plate specimen that has been securely tightened into place in the grounding vice. A proper ground is checked by consulting the weld gun chuck voltage display in the data acquisition (DAQ) program. The researcher proceeds to the DAQ computer and enters all relevant information the values of all parameters into the user interface, to be recorded for documentation of data. See Fig 3. for a picture of the user interface. Next, the exhaust system is turned on from the DAQ program, and the weld is initiated remotely from the DAQ program. When the weld is completed, it is examined and all relevant information is recorded using the DAQ user interface. The weld is given an identification number based on the date and the number of welds performed that day. The data file is saved and the procedure is repeated.



Welder: Nelson Nelweld
Current: 1500 Amps
Weld Time: 0.900 sec
Hot Plunge: 0.100 sec
Lift: 1/16"
Plunge: 1/4"
Dampening: 1.00 turns
Material: Carbocoat w/ Deck
Shielding: None
Ferrule: Full Ferrule
Reason: Experiment Matrix
Comments: The user can manually make notes of unique conditions prior to the weld in this text box.

Time: 04 Oct 2006 - 03:49 PM
Researcher: Ted Swanson
Welder: Nelson Nelweld
Current: 1750 Amps
Weld Time: 0.900 sec
Hot Plunge: 0.100 sec
Lift: 1/16"
Plunge: 1/4"
Dampening: 1.00 turns
Material: Carbocoat w/ Deck
Shielding: None
Ferrule: Full Ferrule
Reason: Experiment Matrix
Sampling Rate: 60kS/s
Pre-Weld Comments: The user

Chuck Voltage: 0.02
Researcher in Charge: Ted Swanson

Outcome: Successful
Flash: ¾ Perimeter
Flash Depth: Filled Ferrule
Bondline: Full Bondline
Expulsion: Metal Droplet
Zinc Plume: Significant Plume
Comments: Any further qualitative or quantitative post weld notes can be added here.

Outcome:
Flash:
Flash Depth:
Undercut:
Expulsion:
Zinc Plume:
Post-Weld Comments: N/A

Time: 04 Oct 2006 - 03:57 PM
Researcher: Ted Swanson
Welder: Nelson Nelweld
Current: 1500 Amps
Weld Time: 0.900 sec
Hot Plunge: 0.100 sec
Lift: 1/16"
Plunge: 1/4"

Folder to Save To: 13 DOE Series 2

04 Oct 06, Wednesday, 03:56:16 PM

Fig. 9 – DAQ user interface. Upper left is pre-weld information, upper right is weld initiation, lower left is post-weld information, and lower right is final check and file saving.

Studs were tensile tested in a calibrated Instron tensile testing machine using a fixture constructed as per AWS D1.1-Section 7. Maximum load values were recorded for each weld, and were normalized to stress by using the area of the stud. Tensile testing was used to obtain a discrete value as a response variable, as opposed the pass/fail response of a field bend test.

4.0 RESULTS AND DISCUSSION

4.1. Design if Experiment, Pareto Chart

The advantage of using a design of experiments (DOE) statistical approach to experimentation is that it allows for the analysis of interaction between variables. In contrast, the traditional method of experimentation, where one variable is incremented while all others remain constant, does not take into account the influences of one variable on another.

The reason this type of experiment was used to examine stud welding was because of the large number of variable that interact. The variables examined in the initial DOE were weld time, weld current, lift distance, plunge depth, and plunge dampening, all variables that can be set by the operator prior to welding. This testing revealed that most important factor was the interaction of lift and dampening, as can be seen by Figure 4 below. The second most influential factor was current. This fact that these two factors were important point to the fact that power delivered to the weld area is an important consideration. This can be drawn from the fact that power is the product of current and voltage; voltage can be correlated to lift distance (arc length), two variables that are prominent in the DOE analysis.

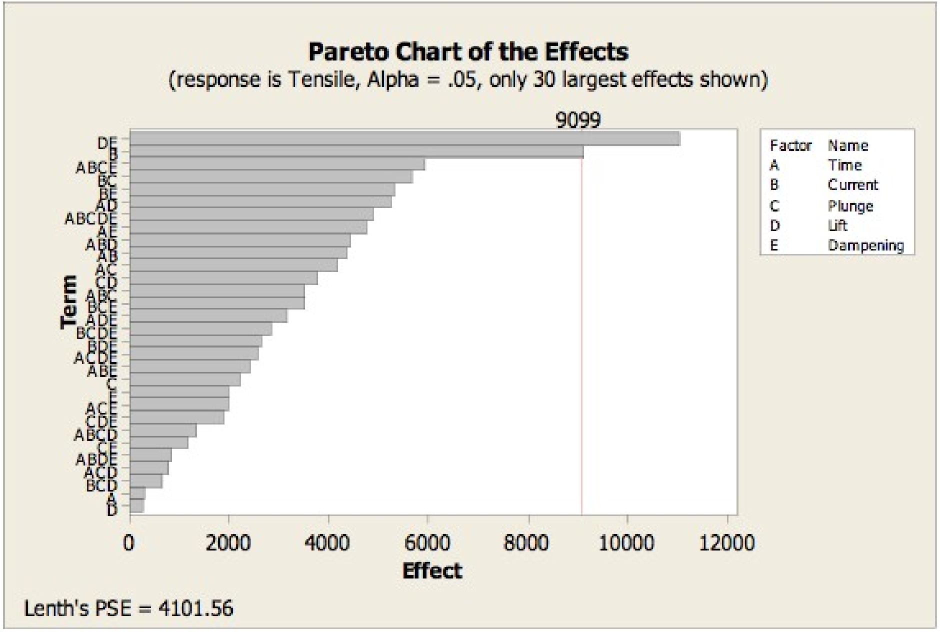


Fig. 10 – Pareto chart showing the relative importance of interactions between variables.

4.2. Contact Resistance, Initial Stage of welding ("pilot arc")

During the first few milliseconds of welding, Stage I resembles a resistance welding process in which Joule (resistive) heating occurs. For a given current and time, this effect is mostly dependent on the contact resistance between the stud and the base metal, when the force is also constant.

This is significant because of the elimination of the coating was largely complete by the time the 100 amp level was reached. During an actual weld cycle this 100 amp threshold is crossed within the first millisecond, indicating that the coating at the location in which the weld is taking place is most likely burnt through during the initial stages of the weld. It would therefore be largely incapable of affecting the quality of the weld in any capacity other than as a contaminant – and this only occurs if it is not completely burnt up during the weld cycle or expulsed from the weld during the forge welding phase.

Steel Wool Innovation. This idea (shown in Figure 11) was intended to preheat the coatings at the interface and remove them before the actual welding cycle (drawn arc) starts.

Figure 11. Steel wool packed inside the ferrule before welding

Indeed, arc initiation was improved using this technique (see Appendix II) on all coatings. However, arc stability was negatively impacted by the vaporized residue of steel wool during subsequent welding, resulting in porosity and lack of fusion type defects. More work is required to further develop this promising idea, such as using a steel mesh instead of steel wool, as well as adding arc stabilization elements such as rare earths and organics to the stud-metal interface.

4.3. Arc Blow

As mentioned in the Introduction Section, the presence of arc blow in drawn arc stud welding is the culprit for a significant portion of weld failures. Arc blow is the phenomenon generally described by a “wandering” arc, or an arc that does not travel from the shortest path from the electrode to the workpiece. Magnetic flux lines which denote the magnetic field density at a point always are in concentric circles around the current path. As the current path bends a sharp right angle as it exits the electrode (stud) and enters the workpiece, a buildup of magnetic field lines can be imagined along the inner radius of the curve while the flux lines around the outer radius of the curve become spaced further apart. An analogy can be drawn when bending a pipe: the interior radius may “bunch up” due to excess material while the outer radius will be stretched very thin. In the case of magnetic arc blow, the arc will be driven to the far side of the current return path in search of a larger turning radius needed to balance the magnetic fields. As shown in the diagram below, the red arrow shows the direction of the force on the arc due to arc blow, the blue arrow shows the direction and relative magnitude of the force on the arc due to a corrective magnetic field, and the green arrow shows the net effective force on the arc.

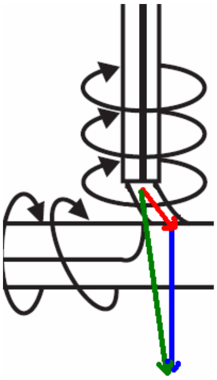


Fig. 12–Illustration depicting the concept of arc blow.

Interestingly, there is a steady-state balance due to the higher magnetic permeability of the steel workpiece on the outer radius as compared to air encountered on the inner radius. (Magnetic permeability is the ease through which magnetic field lines will travel through a particular material.) The magnetic flux around the interior of the radius of curvature due to current path geometry will equal the magnetic flux “trapped” by the easier path through the steel on the outer radius once the arc has been deflected a sufficient angle.

To minimize arc blow, either the magnetic field rings induced around the current path must be rearranged or cancelled. Redirecting the magnetic fields via arresting would be difficult due to the relative orientation of the current return path with respect to the gun. Canceling the magnetic field could be accomplished by the superimposition of a field opposite and equal in magnitude to the magnetic field causing the arc blow.

4.3.1 Arc centering Solenoid solution. One approach taken was to build an Arc Centering Solenoid – a coil external to the process that would envelop the end of the stud during the weld cycle. A current running through the coil would create a magnetic field running primarily through the stud and directed downward toward the workpiece. Although the imposed field is not the negative of the magnetic field induced by the main current, vector addition of the two fields would yield a net force pointing into the workpiece as shown in the previous illustration.

Fig. 13 – Arc Centering Solenoid (ACS) before mounting on the stud welding gun, replacing the support fork/legs.

The arc centering solenoid was tested at several power levels. At the lowest power levels, 0W to 4W, the ACS was not powerful enough to produce a force strong enough to counteract arc blow. At larger power levels, 12W to 50W, the ACS became increasingly restrictive on the arc. At the highest power setting, 75W, the ACS produced a magnetic field strong enough to pinch off the arc shortly after being drawn. The most effective power level tested was around 6.4W, which corresponds to a delivered current of 0.80A into the 10Ω solenoid. As seen in the pictures below, low current settings resulted in gross undercut, and high current settings resulted in a “spattered” and porous weld.

The best weld exhibited a half perimeter flash and full metal bond line. The ACS at its highest power setting, 2.75A at 75W, did not form a weld due to the extinguished arc.

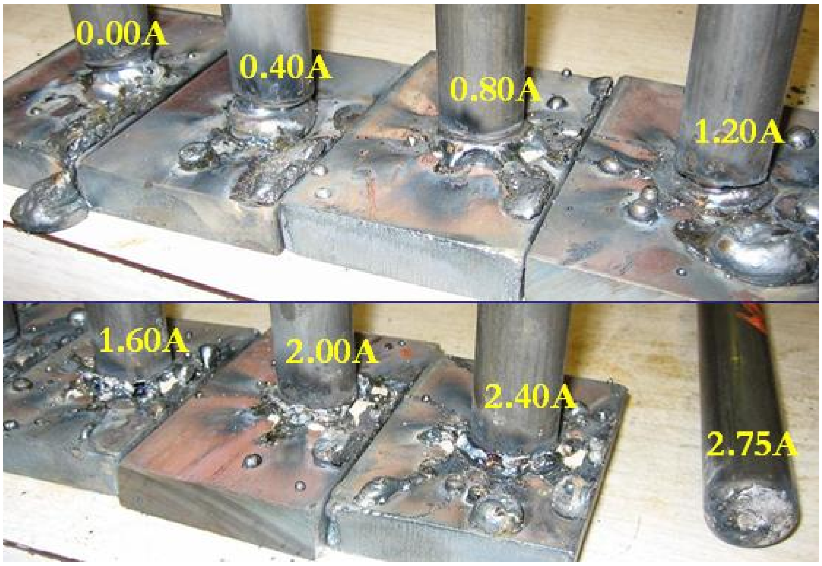


Fig. 14 – Results from ACS testing revealed an optimal ACS power operational window.

4.3.2 Pulsed Waveform Solution

The power supply used for this project was a Miller PowerCon, a prototype inductive power supply. The team was able to directly access the controller and thus reprogram it. The power supply operates from two main files: a list of constants, and a state machine. The state machine is a scan type program that monitors a number of variables and responds appropriately as they are changed. The machine operates at approximately 1000Hz.

To modify the supply from DC to pulsed DC, a number of variables were added to the constants file:

- I_MAX – peak current (A)
- I_MIN – background current (A)
- TIMER_H – time to maintain peak current for each cycle (ms)
- TIMER_L – time to maintain background current for each cycle (ms)

Because the machine cycles at approximately 1000Hz, one cycle is roughly equivalent to one millisecond. This simplifies the task of determining the frequency at which the machine will pulse:

$$f = \frac{1}{TIMER\_H + TIMER\_L}$$

A new function, PULSED_DC, was added to the state machine. The function copies the two timers into new variables, and begins by delivering the maximum current. For each cycle the maximum current is applied, the copied high timer is diminished by one. When this reaches zero, the background current is applied (Figure 15)

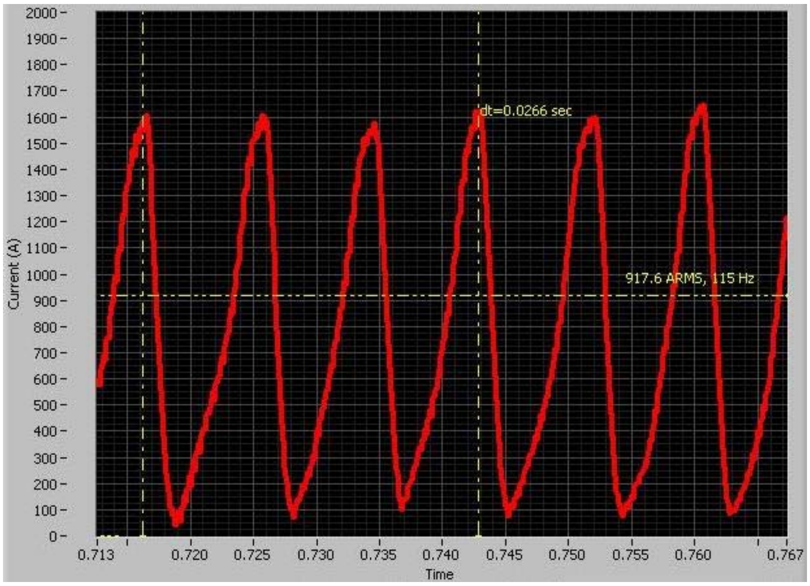


Figure 15. Initial pulsed waveform, Ipeak=1600A, Iback=100A, 115 Hz frequency

*Note: The sections of the Miller code that were changed can be found in appendix 1.

Preliminary testing was performed to find stable pulse parameters that could be used for future testing. Refer to Appendix 2 for preliminary testing parameters. It was determined that argon shielding should be used in order to obtain a larger range of parameters. In order to provide this shielding the Arc Centering Solenoid (ACS) was added to the setup. The testing parameters from the ACS shielded welds can be found in Appendix 3. During these tests it was discovered that the ACS was working passively to help prevent arc blow. Although this is an interesting phenomenon worthy of future study, the ACS was removed so that the original hypothesis, that pulsed DC alone reduces arc blow, could be tested. The parameters from the first series of welds made without the ACS can be found in Appendix 4. At this point it was decided that an alternate method of adding argon shielding should be utilized. A box was built around the welding area and flooded with argon. This system takes advantage of argon being heavier than air to keep the weld area flooded. The welding parameters from these welds shielded without the ACS can be found in Appendix 5.

The PowerCon was initially programmed with the following parameters:

- I_MAX = 1500
- I_MIN = 1000
- TIMER_H = 5 ms
- TIMER_L = 5 ms

Several studs were fired, and the resultant waveforms were examined. The waveforms showed the predicted characteristics. A picture comparing the actual with the predicted waveform can be seen in Figure 16

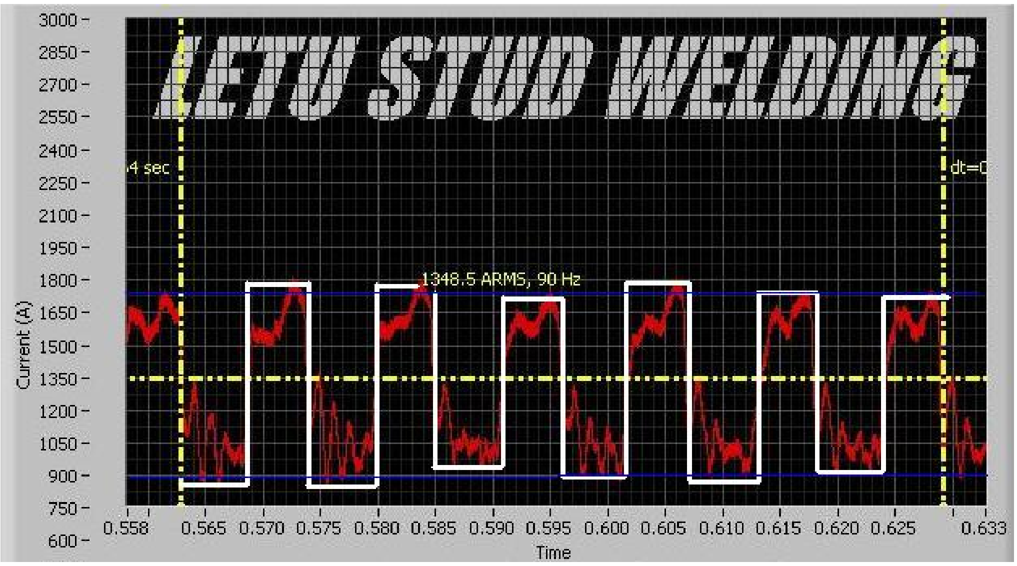


Figure 16. Actual vs. programmed waveform

Once stable pulse parameters were obtained, pulsed welds were made at conditions favorable to arc blow to test the hypothesis. The first method of inducing arc blow involved placing a sheet of fiberglass on all but one side of the test sample to prevent multiple grounding sites. By forcing the current to ground through one side of the sample the arc is forced in the opposite direction. This method was later found to be inadequate and inconsistent with the method used by the senior design stud welding research team. Therefore, a new method of inducing arc blow was devised. This method involved placing a thin strip of steel on one side of the vise and mounting the grounding clamp from the power source to it, ensuring only one grounding path (see Figure 5d). This method established a more effective method of inducing arc blow.

After stable parameters were obtained, a lower background current was desired to obtain a stiffer arc. In order to accomplish this, it was decided that the weld should be shielded in a gas with a higher ionization potential than air. The shielding gas chosen was argon because of its ease of use, properties, and availability. Argon is heavier than air making it easily contained by building a box around the welding area.

The use of argon shielding allowed for lower background currents and higher lift values to be used, which allowed for the creation of higher quality welds.

Passive ACS

It is known that the problems associated with arc blow are increased for longer welding times, as magnetic fields require a certain amount of time to build up. Similarly, it is known that pulsed welding reduces arc blow due to the fact that the magnetic field cannot build to full strength during each pulse, and is therefore diminished on average for the whole weld period.

The phenomenon occurring with the passive ACS in place can be explained in similar terms. When a DC weld is made through the passive ACS, there is no noticeable difference from when the ACS is removed. This is because the eddy currents induced in the shell of the ACS remain constant after an initial start-up time, and only affect the magnetic fields slightly.

However, in a pulsed weld running through the passive ACS, there is a noticeable effect. The initial welding current generates a magnetic field, which induces eddy currents in the shell of the ACS. These eddy currents in turn induce a magnetic field. When the welding current enters the background stage of its period, this magnetic field is just diminishing, and thus helps to center the arc during that background stage, so that it is closer to the center when the welding current begins again.

The voltage drop at the end was closely related to the plunge of the stud into the base metal. This plunge in voltage occurs only in the drop stud section of the program. The phenomenon was also observed on previous constant current weld graphs. It is believed that this drop in voltage is related to arc length and the short circuit established as the stud is plunged into the base metal. As the arc length is decreased, the resistance in the arc decreases causing the voltage also to decrease, as this is a constant current power supply. In order for this theory to be validated the process must be evaluated using high-speed cinematography.

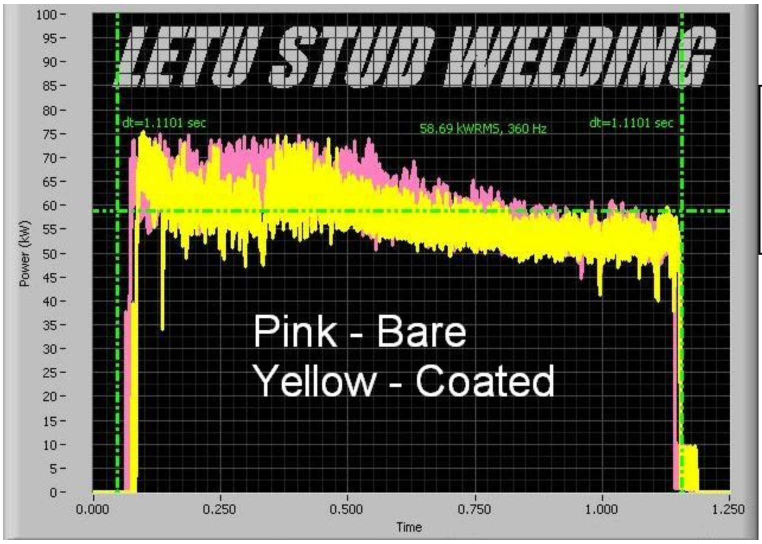


Figure 17. Voltage dropping toward the end of the weld cycle. Also notice no real differences between bare and alkyd paint parameters.

5.0 CONCLUSIONS

Our conclusions are divided based on: a) existing welding power supply technologies, b) proposed modifications using widely available welding equipment and c) new solutions using latest generation of power supplies

5a. EXISTING WELD TECHNOLOGY

Weld quality ranking for different coatings, standard 2,000A rectifier power sources, such as the NelWeld 2000

♦ Operational envelopes for through-deck welding on coated steels were narrower than for bare steels, mostly due to arc instability.

♦ Results were difficult to reproduce because of the inherent process variability and an automated fixture was needed to compare different coatings

♦ Stud weld quality in tensile testing was ranked as function of process reproducibility in the 70-95 kJ arc energy range and using a G90 galvanized decking:

I. Bare (uncoated) steel
II. Alkyd paints
III. Carbozinc coatings (Zn particles in paint)
IV. Hot Dip Galvanized (HDG)

This means that when using the conventional stud welding equipment, insulating paints such as Vulcraft, etc., result in better welds than those performed on any Zn-bearing coating

5b. MODIFIED TECHNOLOGY

This solution still refers to standard 2,000A rectifier power sources, such as the NelWeld 2000

- Designed, built and validated a newly retrofitted Arc Centering Solenoid (ACS) to the stud welding gun to improve process stability and reproducibility when welding on coated steels.

- Optimum prototype parameters were 0.80 Amps at 6.4 W for the ACS with standard parameters on the welding power supply.

- Extra ACS coil weight, current prototype design, was 1.1 kg (2.5 lb). Weight reduction and improved resistance to spatter by using spray deposition ceramic coatings should be the target of the next stage of the work.

- Wiring would introduce two small gauge conductors (one if using a common ground with the power supply) capable of carrying up to 3A that the operator would carry with the other wiring.

- An external power supply for the ACS would be necessary if retrofitting. If incorporated with a new welding power supply, the ACS operating voltage could be matched to that of the lift solenoid in the gun.

5c. NEW WELD TECHNOLOGY:

Based on inverter based prototype 2,000A rectifier power sources, such as the PowCom

- Waveform pulsing improved arc stability and resulting weld quality.

- Optimum parameters were Peak=2000A, Background=900A, at pulsing frequencies between 60-80 Hz. The main problem was lowering the background current under 900A (or increase the frequency) and still maintain an arc.

- The ACS coil (without external power) acted as a passive arc centering and stabilization device.

- Calorimetric measurements confirmed that net heat input was lower in pulsed mode than in continuous wave mode, for the same arc energy.

6.0 RECOMMENDATIONS

Our recommendations are also divided based on: a) existing welding technologies, b) proposed modifications using widely available welding equipment and c) new solutions using latest generation of power supplies

6a. EXISTING WELD TECHNOLOGY

Standard 2,000A rectifier power sources, such as the NelWeld 2000. These ideas are ranked in a decreasing order of importance.

1. Emphasize criticality of arc blow control by symmetrical placement of ground return cable contact points, whenever possible (most important).

2. Avoid coatings with high Zn content. If not possible, develop new Zn-vapor suppression system such as external Argon gas jets or modified stud insert composition.

3. Implement arc energy control, instead of weld current setting control alone

4. Use weld parameter monitoring (steady or drooping arc voltage) to predict weld quality. Avoid parameters resulting in high lifts and rising arc voltages.

5. Continue development of arc-start inserts inside the ferrule using steel mesh instead of steel wool.

6b. MODIFIED WELD TECHNOLOGY

Standard 2,000A rectifier power sources, such as the NelWeld 2000, retrofitted with the external ACS coil

1. Test the new ACS concept on all coatings and examine operational range changes, when compared with no ACS.

2. Improve coil design: lower weight and use ceramic coating to improve resistance to heat and spatter (durability)

3. Validate ACS effectiveness for all coatings and other settings

6c. NEW WELD TECHNOLOGY

Prototype inverter-based 2,000A power sources, such as the PowerCom 2000

1. Complete a cost/benefit analysis to justify using more expensive inverters (compare capital- and maintenance costs, weight, safety implications, etc).

2. Validate the “passive ACS” concept for all coated steels and design new heat resistance, high permeability cylindrical enclosure around the arc.

3. Improve arc stability during pulsing using external gas flow and/or adding low ionization potential elements to the center of the stud or inside the ferrule.

4. Further study the effect of pulsing parameters on the net heat input, as compared to continuous wave

5. Introduce pulsing into the initial arc-start (pilot arc) stage of the stud welding cycle.

7.0 REFERENCES

1. Adonyi, Y. 2006. Through-Deck Stud Welding on Coated Steels, Interim Report to AISC, July 15, 2006

2. Buckner, et al. 2002. Construction Considerations for Composite Steel- and Concrete Floor Systems. Journal of Structural Engineering 1099-1110

3. Pease, Preston. 1972. Stud Welding Through Heavily Galvanized Decking. Welding Journal 241-244

4. Clay, Ramasamy. 2001. Design-of-Experiments Study to Examine the Effect of Different Factor on Drawn Arc Stud Welding, Journal of Materials Processing Manufacturing Science. 251-261

5. Shear Connector Inspection- a Tutorial. 1993 Steel Inspection News, Available [online], http://steelstructures.com/stlInspNews/NEWS%20shear%20stud%20tutorial.htm

6. ISO Standard 13918. Welding-Studs and ceramic ferrules for arc stud welding. 1998 Belmont International Standards Organization Edition 1,

7. ISO Standard 14555 Welding- Arc stud welding of metallic materials. 1998 Belmont International Standards Organization Edition 1,

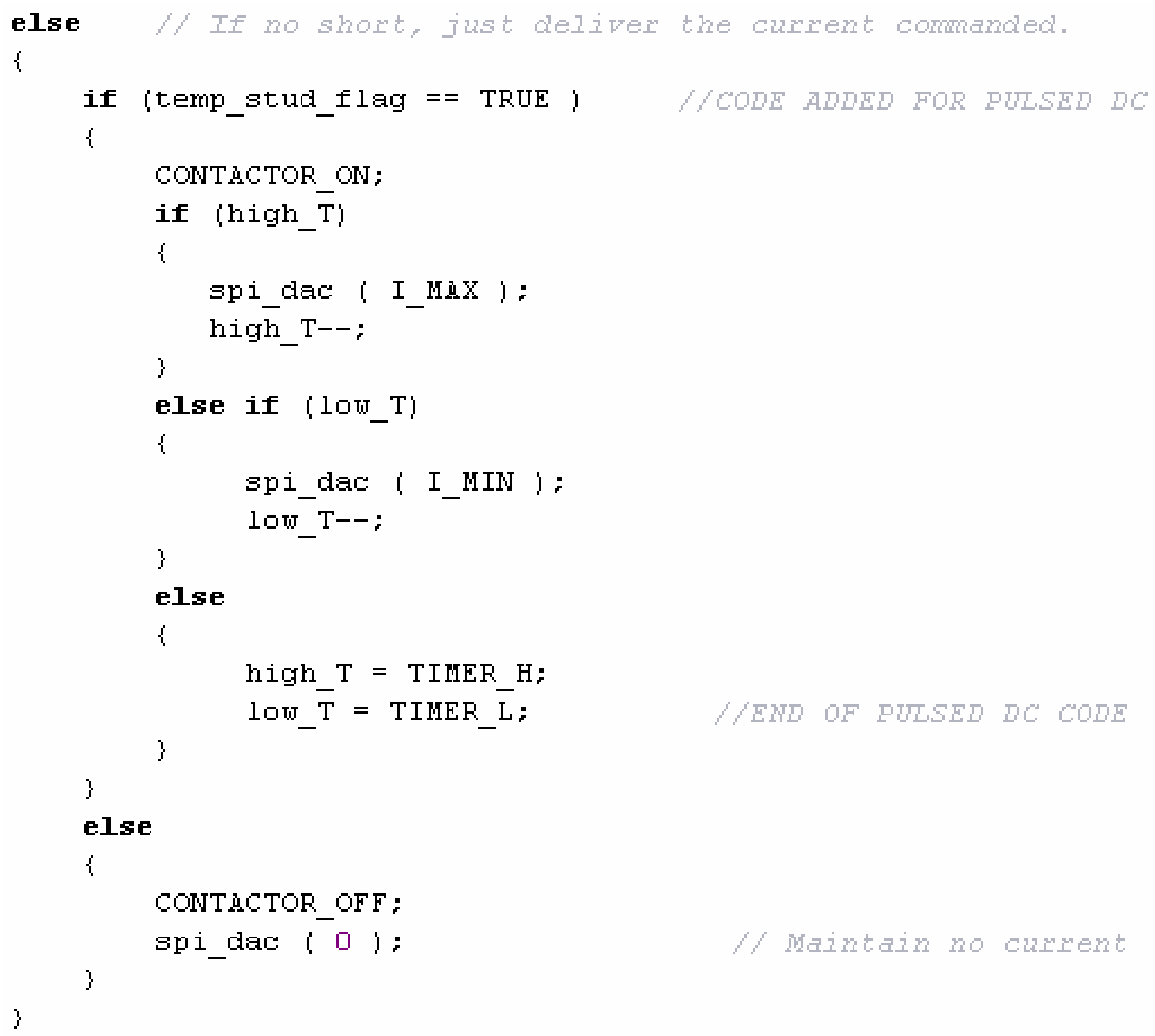
8. AWS Welding Handbook. Vol. 1. 8th ed. pp. 43-54. Miami, FL: American Welding Society, 1987.

9. AWS Welding Handbook. Vol. 2. 8th ed. pp. 2-42 and pp 299-327. Miami, FL: American Welding Society, 1991.

10. Structural Welding Code – Steel, ANSI/AWS D1.1. 16th ed. pp 223-228 and pp. 415-416. Miami, FL: American Welding Society, 1998.

11. The Physics of Welding. J.F. Lancaster, Pergamon 1st Edition 1984. pp 50-200.

Appendix 1



```
else    // If no short, just deliver the current commanded.
{
    if (temp_stud_flag == TRUE )      //CODE ADDED FOR PULSED DC
    {
        CONTACTOR_ON;
        if (high_T)
        {
           spi_dac ( I_MAX );
           high_T--;
        }
        else if (low_T)
        {
             spi_dac ( I_MIN );
             low_T--;
        }
        else
        {
             high_T = TIMER_H;
             low_T = TIMER_L;          //END OF PULSED DC CODE
        }
    }
    else
    {
        CONTACTOR_OFF;
        spi_dac ( 0 );                   // Maintain no current
    }
}
```

```
/*********************Lee's amazing pulsed DC constants *******************/

#define TIMER_H                     5       // # of cycles for I_MAX
#define TIMER_L                     5       // # of cycles for I_MIN
#define I_MAX                       1500    // amps
#define I_MIN                       500     // amps
```