INFLUENCE OF WATER TEMPERATURE AND FLOW ON ELECTRODE LIFE

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ABSTRACT:

Much study has been made to determine the best copper alloys required to produce high quality welds and long life when resistance welding steel and particularly galvanized metal. New electrode designs that use unique geometry have been developed to accomplish the same results. Additionally, many control schemes have been developed to enhance welding of galvanized steel while maintaining reasonable electrode life.

In all of this development, it has been assumed that water temperature and flow rate was of low importance in the welding equation as long as **some** flow was present. In fact, many large users have taken conflicting stands on the importance of having low temperature water flowing through the electrode holders.

This paper will undertake the task of evaluating electrode life under various water temperature and flow conditions. Testing will be done on both galvanized and CRS material.

Additional examination will be done to quantify the effect on electrode life verses the cooling tube position within the electrode holder.

INTRODUCTION:

Resistance welding is generally considered to be the most economical method of joining sheetmetal. Unfortunately the quality of such joints can vary considerably as a result of many variables in the process. Advances in welder controls and welder mechanical systems has minimized if not reasonbly eliminated many of these variables (ie. weld time and current).

It is not unusual to observe a resistance welding line where metal expulsion flows freely and welder electrode faces are mushroomed to the point where it is impossible to tell the original shape. Charts, such as that shown in FIGURE 1, have been published showing the effect on electrode face diameter changes to weld current density. However a search of the literature could produce no definitive study showing **how** to control this diameter change or the effect on weld strength and appearance.

BACKGROUND:

Well recognized texts on resistance welding cover the subject of water cooling in one or two paragraphs. For example, the AWS welding handbook[1] says that, "Wherever practical, spot welding electrodes should have an internal cooling passage extending close to the welding face. This passage should be designed to accommodate a water inlet tube and to provide for water flow out around the tube..." No mention is made of a recommended temperature or flow rate.

The RWMA welding handbook[2] notes the importance of water cooling "to maintain the mechanical and physical properties..." of the electrode. The section continues, "...the cooling water flow rate should be a minimum of 1-1/2 gal/min per tip and the incoming water temperature should not exceed 50°F. These ideal conditions are not always attainable under production conditions and lower values will impact electrode life."

Neither of these two handbooks addresses the relationship between cooling water and weld quality. Additionally, no figures are presented to support the stated flow and temperature values.

In an SME paper on electrodes[3], heat flow to the electrodes was, as shown in FIGURE 2, produced

FIGURE 1: EFFECT OF ELECTRODE MUSHROOMING ON WELD

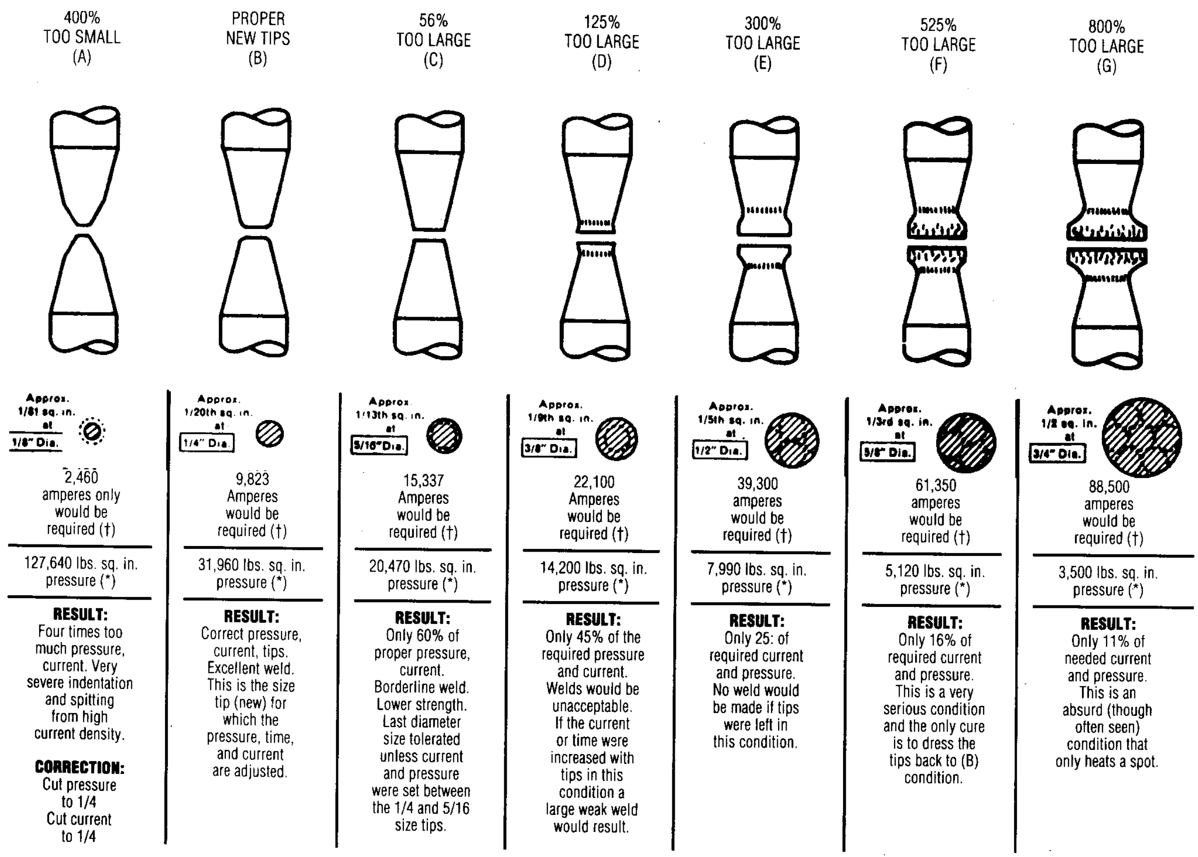
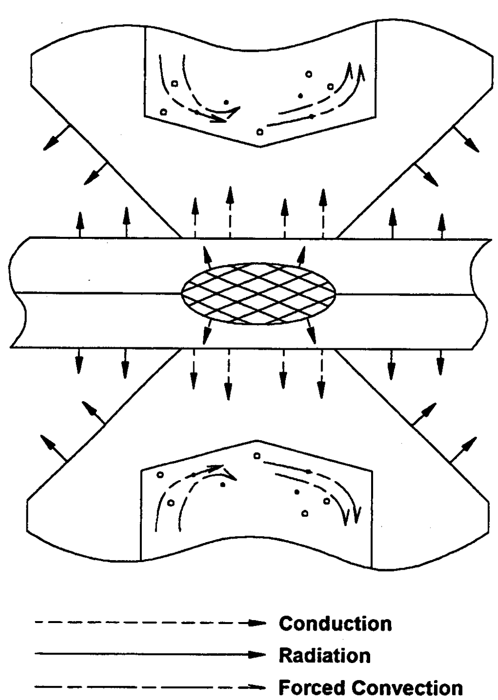


FIGURE 2: HEAT INPUT TO ELECTRODE



by CONDUCTION and RADIATION. Formulas were included in the paper to calculate heat transmission from these two sources.

For heat TRANSFERRED by CONDUCTION, the formula is:

$$K=Q/[A*(T_1 - T_2)/X]$$

where Q = the heat flow rate of the material, A = the cross sectional area of the product, T_1 = the temperature of the area that needs the heat removed, T_2 = the temperature of the cooler surrounding material, and X = the heat flow path.

For heat TRANSMITTED by RADIATION, the equation for heat transfer was expressed as:

$$Q = A*e*u*(T)^4$$

where A = the area of the surface radiating heat, e = the emissivity value of the material (at a given temperature), u = Stefan-Boltzmann Constant, and T = the temperature of the surface.

The paper also presented a formula to calculate the heat REMOVED by water inside the electrode:

$$Q = h*A*(T_f - T_s)$$

where h = the convective surface material coefficient, A = the surface area transferring heat, T_f = the fluid bulk temperature, and T_s = the solid bulk temperature.

Once the heat transfer is known, it must be factored over the time of contact between the electrode. Then this effect must be computed with the electrode force density (lb/psi) and the physical properties of the electrode alloy to predict geometry change of the electrode.

It is possible to formulate mathematical models utilizing such equations to predict behavior of electrodes under temperature and force over time. However in the real world of production welding, application of such models is often not practical. In addition, models that can predict physical results in a laboratory setting often fail to match reality in the real world of production resistance welders.

This paper undertakes the analytical task of examining factory condition high speed resistance welding as it effects electrode life and weld quality with respect to changes in cooling water temperature and flow.

TEST METHODOLOGY:

For this paper, a 50 KVA press welder with a 12" deep throat was connected to a 12,000 BTU/Hr water chiller[4] in series with a 14,000 BTU/Hr electric water heater. The system was controlled by a thermostat that balanced the water chiller and water heater to produce desired temperatures for various tests.

Water flow was separately and accurately controlled in both the upper and lower electrode holders. Flow in each electrode cooled holder was metered by a water flow instrument[5] that allowed setting from 0-100 gph (0-1.67 gpm). The metering was placed on the return side hose for each water cooled electrode holder. The two water cooled electrode holders were plumbed in parallel for all tests.

For all but one series of tests, commercially available electrode holders[6] were used that contained a spring loaded sliding water tube that forced the diagonal cut end of this tube fully to the bottom of the electrode interior hole as shown in FIGURE 3.

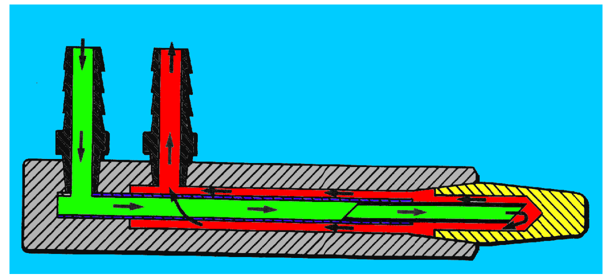


FIGURE 3: HEAT REMOVAL FROM ELECTRODE HOLDER

This eliminated the variable of sliding tube position in the tests. Note that one test used a holder without this spring system to allow purposeful retraction of this sliding tube.

A microprocessor based welder control[7] was used in the "constant voltage" mode. In this way, variables of weld time and weld voltage were eliminated. This control also employed a solid state differential pressure transducer to start each weld at a precise electrode force. The control calculated electrode force by the formula:

ELECTRODE FORCE = DIFFERENTIAL PRESSURE * WELD CYLINDER AREA

The use of a differential transducer in the test eliminated the effects of flow control variations in the pneumatic system. Also included in the control was a secondary weld current monitor to document the system output. Welder transformer tap positions were selected for each test to allow HEAT% to remain between 70% and 90%.

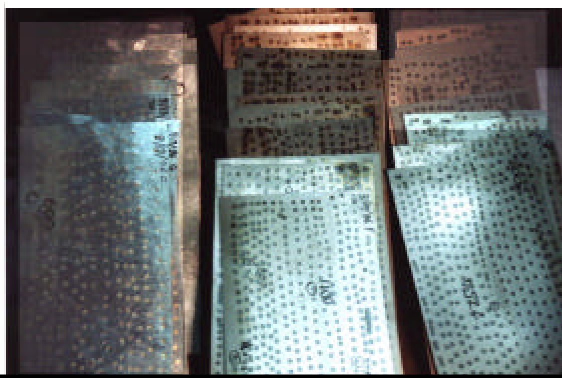
SELECTION OF MATERIAL FOR TESTING:

There are obviously a very large range of metal thicknesses, alloys, and coatings used in resistance welding. This paper covers three of these materials: .029 1010 CRS bare, .050 1010 CRS bare, and .031 1010 CRS G90 galvanized.

MAKING WELDS:

At the start of each test series, two size 5RW pointed type A male cap electrodes were installed in 1-1/2" shanks and 50 welds were made to allow preconditioning. For the two bare steel runs, RWMA Class 2.1820 copper chromium alloy was used[8]. RWMA Class 2.18150 chrome zirconium copper alloy was used[9] for tests on G90 galvanized steel.

FIGURE 4: THOUSANDS OF TEST WELDS



To reproduce high production conditions, welds were made on two 12" X 24" sheets with welds spaced approximately 1" apart in rows spaced approximately 3/4" (see FIGURE 4). In all, over 90,000 welds were made on three different material groups in the research for this paper.

The welding control was set in the repeat mode to produce continuous rates:

54 welds per minute were made on the CRS runs representing 2,970 welds in a 55 minute production hour.

42 welds per minute were made on the galvanized runs representing 2,310 welds in a 55 minute production hour.

AT NO TIME DURING ANY TEST WERE ELECTRODES DRESSED OR OTHERWISE CLEANED OR ADJUSTED.

The control was set to stop the welder every 100 welds on the galvanized steel and every 250 welds on the bare steel. At that time, a sample weld was made using two 3/4" X 3" coupons overlapped 3/4" as recommended by the RWMA[10]. The welded coupon was then placed in a tensile tester and pulled as shown in FIGURE 5 to obtain peak values.

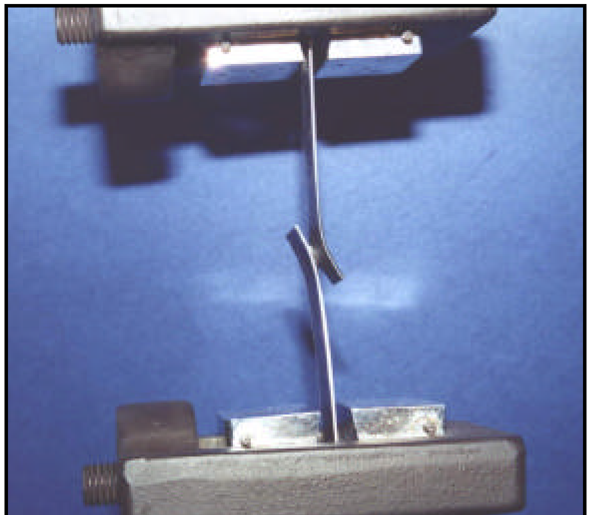


FIGURE 5: TENSILE TEST OF WELD COUPON

FIGURE 6: HUNDREDS OF TENSILE TESTS

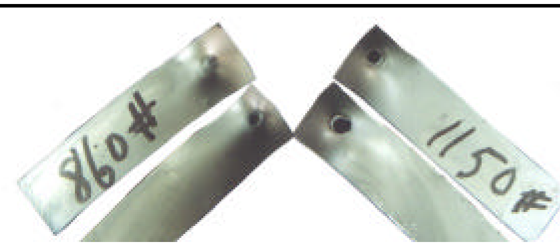


FIGURE 7: Weld Nugget Peal Tests

For this paper, over 500 tensile tests were performed (see FIGURE 6).
At the same time, another coupon was mechanically pealed to produce a weld nugget for measurement. FIGURE 7 shows two typical nugget peal tests to illustrate the visual relationship between tensile value and nugget diameter. A nugget peal test provides information on the ductility of the weld.

Lastly, the electrode face diameter was measured using a digital caliper. It was noted early in testing that the lower electrode tended to have a growth in diameter of approximately 5% over the upper electrode. Since the welding current is identical through both electrodes (series electrical circuit), it was concluded that this was caused by the fact that the lower electrode was in contact with elevated temperatures on the part longer during each weld. Measurements used in data for this paper were the average of the upper and lower electrode dimensions.

WATER TEMPERATURE AND FLOW CONDITIONS:

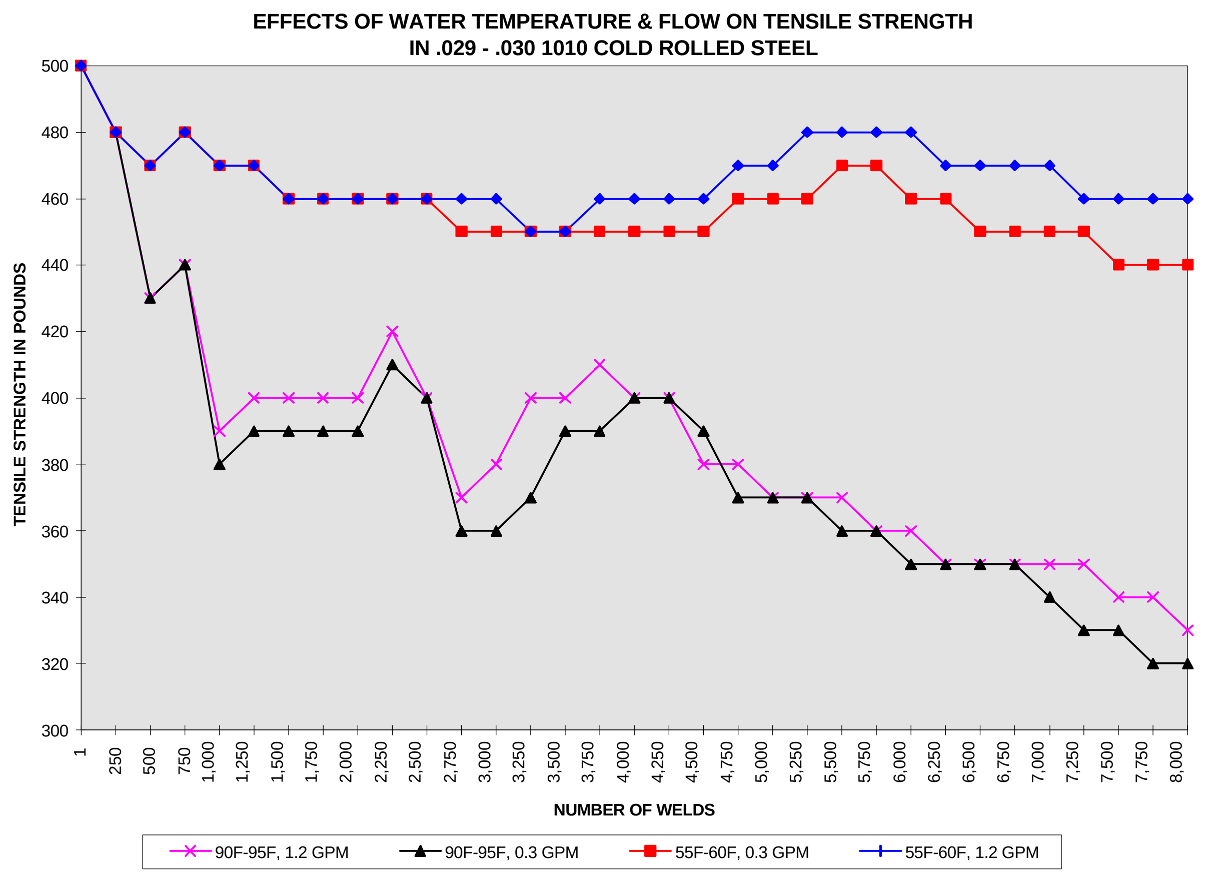
Since this paper covers physical testing rather than computer modeling, it was not practical to try every matrix of water temperature and flow. Therefore it was decided to use the following four combinations as reasonable representations of typical factory conditions:

1. Water temperature = 55°F-60°F, water flow = 1.2 gpm
2. Water temperature = 55°F-60°F, water flow = 0.3 gpm
3. Water temperature = 90°F-95°F, water flow = 1.2 gpm
4. Water temperature = 90°F-95°F, water flow = 0.3 gpm

RESULTS ON .029 CRS 1010, BARE, LIGHT OIL:

The welding control was set with the following pa-

GRAPH 1



rameters:

SQUEEZE TIME = 00 cycles (fires from transducer signal)
WELD TIME = 8 cycles
WELD CURRENT = 8,100
HOLD TIME = 03 cycles
ELECTRODE FORCE = 400 LB.

GRAPH 1 shows TENSILE test values for the four conditions of water temperature and flow. The actual values can be found in APPENDIX A through APPENDIX D. There were 8,000 welds done for each of these four combinations.

Tensile values started to drop at about the 500 weld point for the two higher temperature water runs. These values continued to drop and did not appear to stabilize during the test. By weld 8,000, the tensile value had dropped an average of 35%.

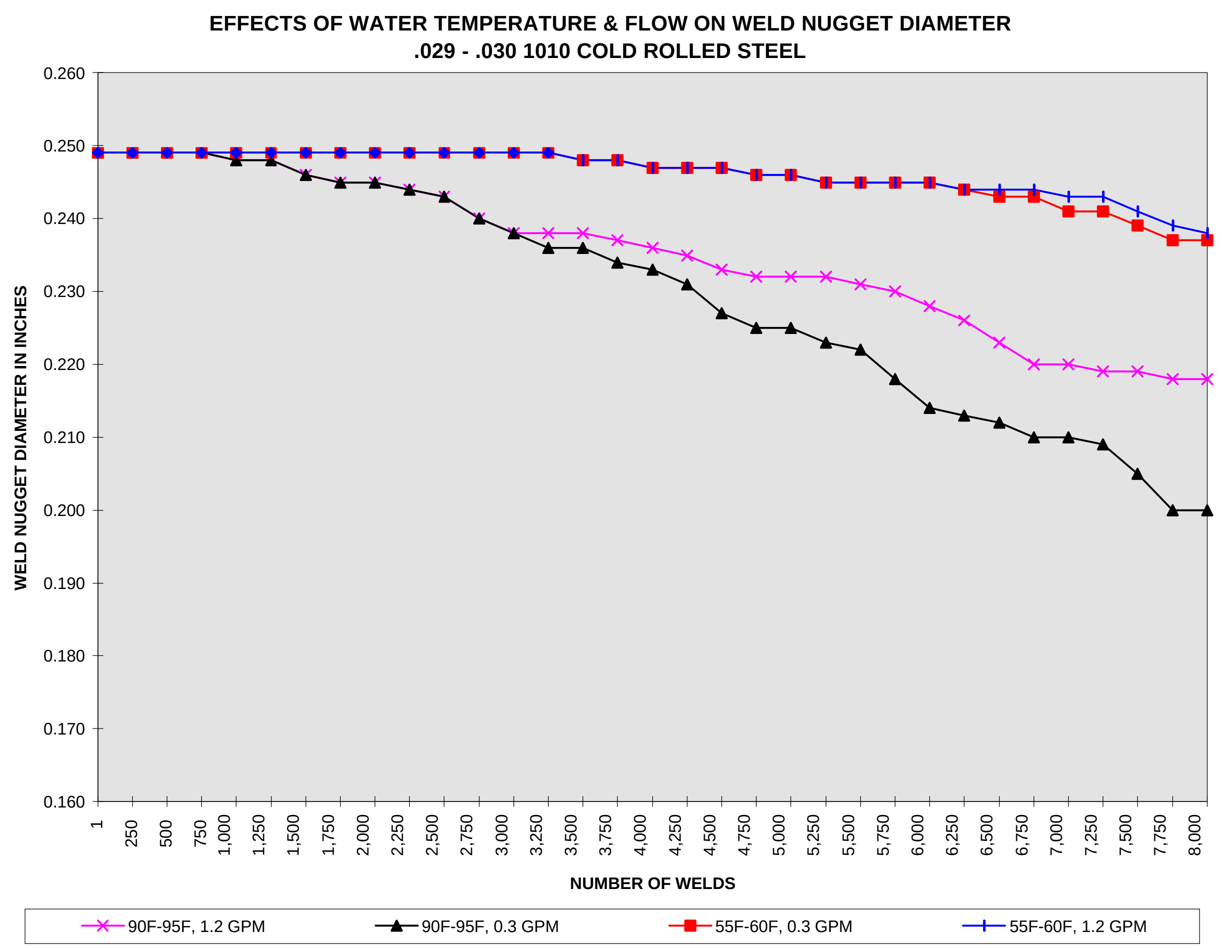
Conversely, the two tests run with lower temperature water equalized at about 1,250 welds and continued through the end of the run with slight increases at about 5,000 through 5,750 welds. The last values recorded showed an average decrease in tensile strength of 10% for these two runs.

In both higher and lower water temperature runs, the difference between the 1.2 gpm and 0.3 gpm flows did not appear to have a significant on the tensile values. On the two lower temperature runs, the difference started to occur after approximately 3,500 welds and continued through the end of the runs where it averaged 3%.

GRAPH 2 plots the WELD NUGGET diameter over the 8,000 welds for the four water conditions.

On the two higher temperature runs, the nugget diameter started to decrease at the 500th. weld and continued in an almost straight line manner through weld

GRAPH 2



8,000. The percentile decrease for these higher temperature runs averaged 16%.

On the two lower temperature runs, the nugget diameter was basically unchanged through weld 3,250 and then decreased in an almost straight line to an average of 4.6% lower at weld 8,000.

The effect of lowering the water flow on the two lower temperature runs produced a minimal 0.4% difference.

Lower water flow on the two higher temperature runs produced a more pronounced difference of 7.3% .

GRAPH 3 tracks the ELECTRODE contact face diameter for each of the four water conditions.

The two higher temperature runs started to show increases in electrode face diameter at weld 750 and continued in an almost straight line through weld 8,000. At the end of these two runs, the diameter had increased an average of 43.6%.

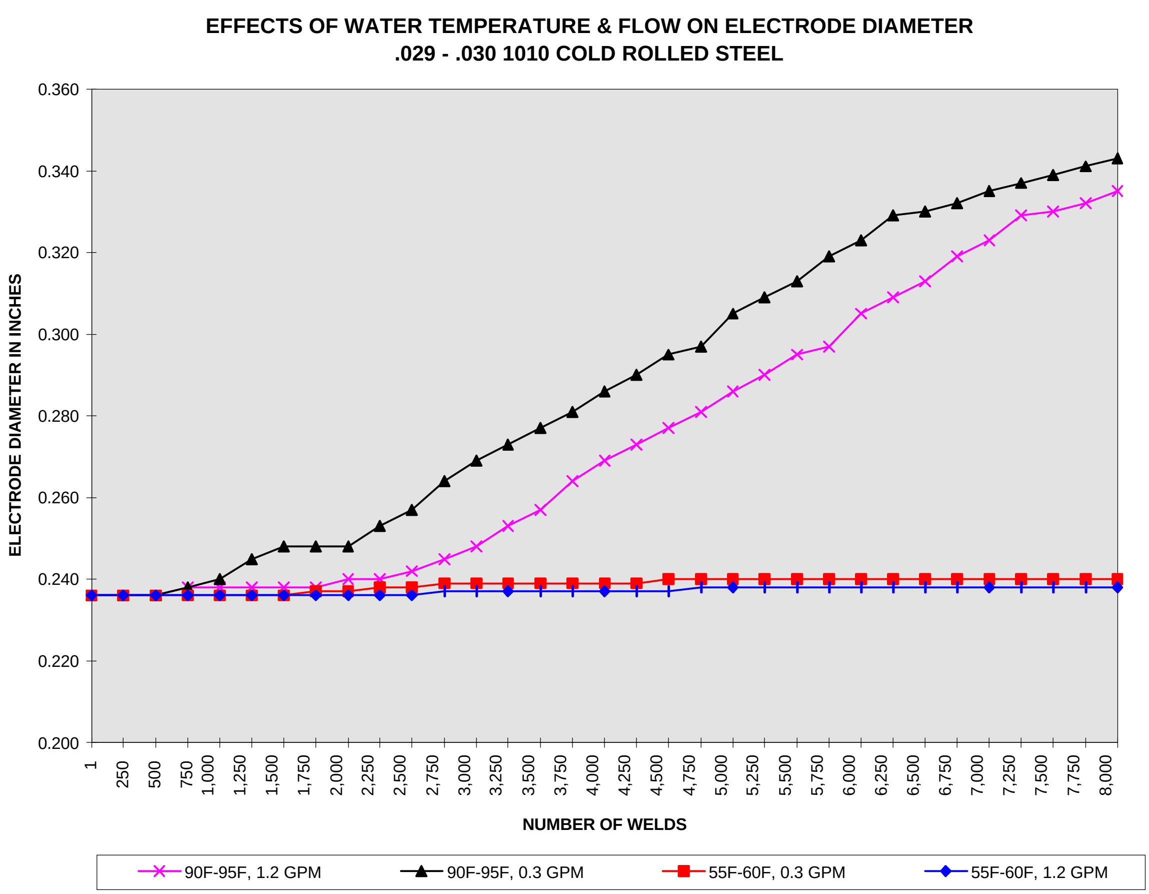
On the two lower temperature runs, electrode contact diameter remained constant through weld 8,000 with the final diameters being equal at an increase of 0.8%.

There was no effect from water flow changes on the two lower temperature runs. However, lower water flow on the higher temperature runs showed a difference starting at about weld 5,000 through 8,000 with ending percent differences of 3.4%.

APPENDIX A through APPENDIX D also track the point when electrodes started to stick after each weld. On the two lower temperature runs, no sticking was noted through weld 8,000. On the two higher temperature runs, the advent of sticking occurred at weld 5,500 and continued through the end of the runs.

These tables also gives weld surface condition. On the two lower temperature tests, the weld nugget remained clean and symmetrical for each of the 8,000

GRAPH 3



weld runs. The higher temperature runs started to show irregular shape patterns on the exterior of the welds at weld 2,500 and then an increase in nugget zone depth at weld 4,250. At the very end of both higher temperature runs, the nugget area was noticeably rough. This was a match to the pitting of the electrode face.

The last area observed is shown in the ELECTRODE CONDITION columns of the four tables. This follows the physical appearance of the electrodes through each run.

FIGURE 8: ELECTRODES AFTER 8,000 WELDS ON .029 CRS

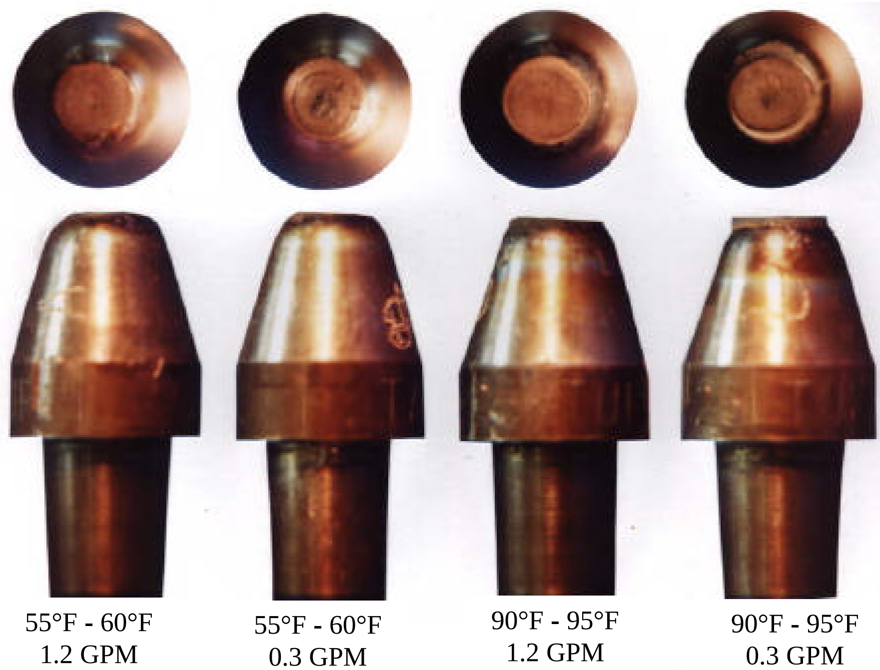


FIGURE 8 shows photographs of the electrodes after 8,000 welds. Electrodes used in the lower temperature tests are almost unchanged whereas the electrodes using higher temperature water have noticeable deformation and diameter change. On the higher temperature runs, visual distortion of electrodes was observed at weld 2,750, visual mushrooming at weld 3,500, and discoloration of the electrode and shank at weld 5,000 for both water flow runs. There appeared to be no difference between the low and high water flow runs.

RESULTS ON .050 CRS BARE:

The welding control was set with the following parameters:

SQUEEZE TIME = 00 cycles (fires from transducer signal)
WELD TIME = 12 cycles
WELD CURRENT =10,500
HOLD TIME = 03 cycles
ELECTRODE FORCE = 650 LB.

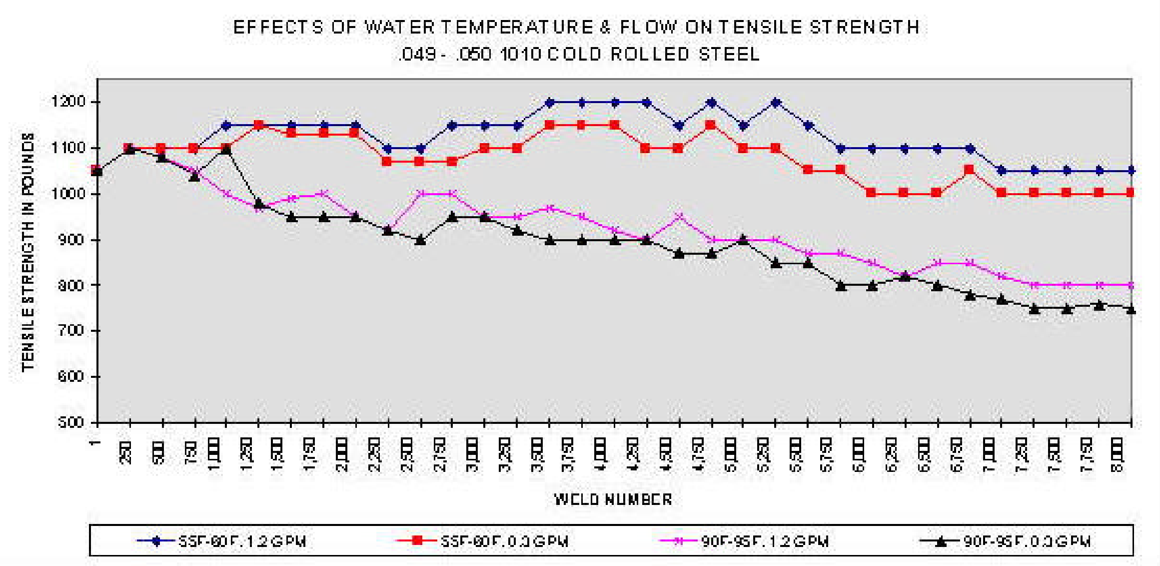
GRAPH 4 shows TENSILE test values for the four conditions of water temperature and flow. The actual values can be found in APPENDIX E through H. There were 8,000 welds made for each of these four combinations.

Tensile values started to drop at about the 750 weld point for the two higher temperature water runs. These values continued to drop and did not appear to stabilize during the test. At the end of 8,000 welds, weld tensile values decreased an average of 26.2%.

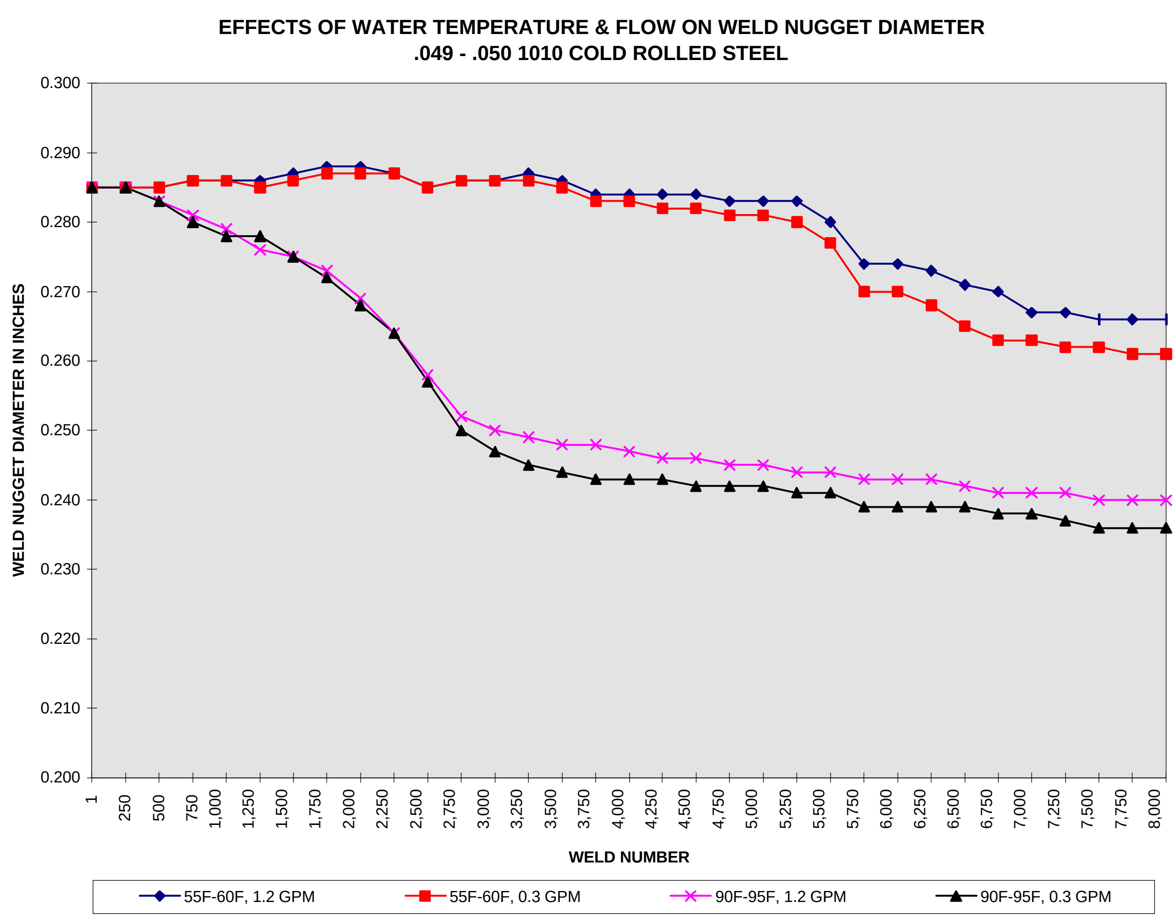
The two tests run with lower temperature water equalized at about 1,000 welds and continued through the end of the run with only minor variations. Tensile on weld 8,000 for both runs decreased an average of 2.4%.

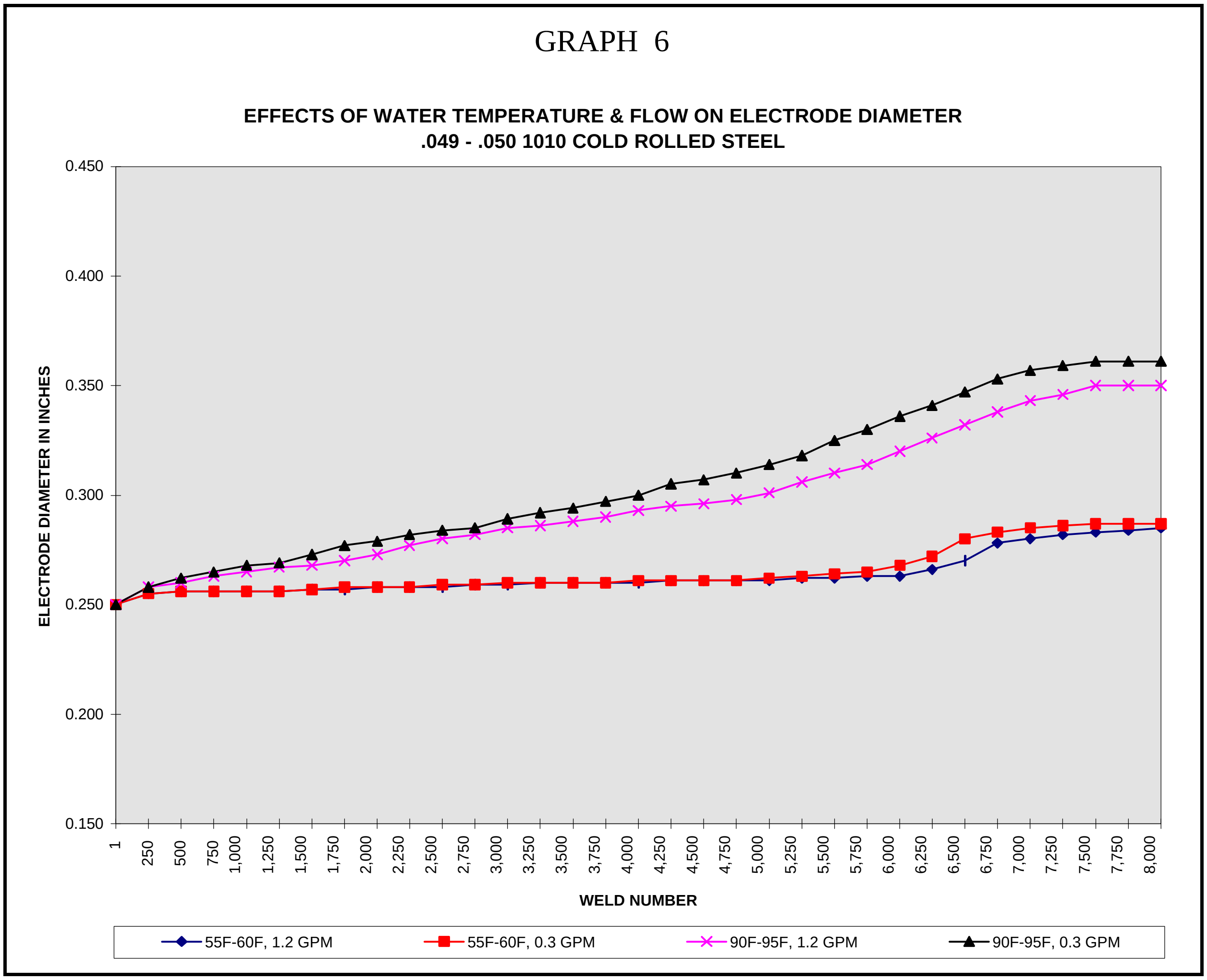
In both higher and lower water temperature runs, the difference between the 1.2 gpm and 0.3 gpm flows did not appear to have a significant effect on the tensile values. Both runs showed an approximate 5% variation from about weld 2,000 through 8,000 ending at

GRAPH 4



GRAPH 5





4.8% a reduction in tensile.

GRAPH 5 plots the WELD NUGGET diameter over the 8,000 welds for the four water conditions.

On the two higher temperature runs, the nugget diameter started to decrease at the 750th. weld and continued in an almost straight line manner through weld 8,000. At the end of 8,000 welds, the nugget was had been reduced in diameter an average of 16%.

On the two lower temperature runs, the nugget diameter was basically unchanged through weld 5,250 and then decreased in an almost straight line to 6.6% at weld 8,000.

BBy the end of 8,000 welds, the average difference between the low and high water flow for both higher and lower temperature pairs was 1%.

GRAPH 6 tracks the ELECTRODE contact face diameter for each of the four water conditions.

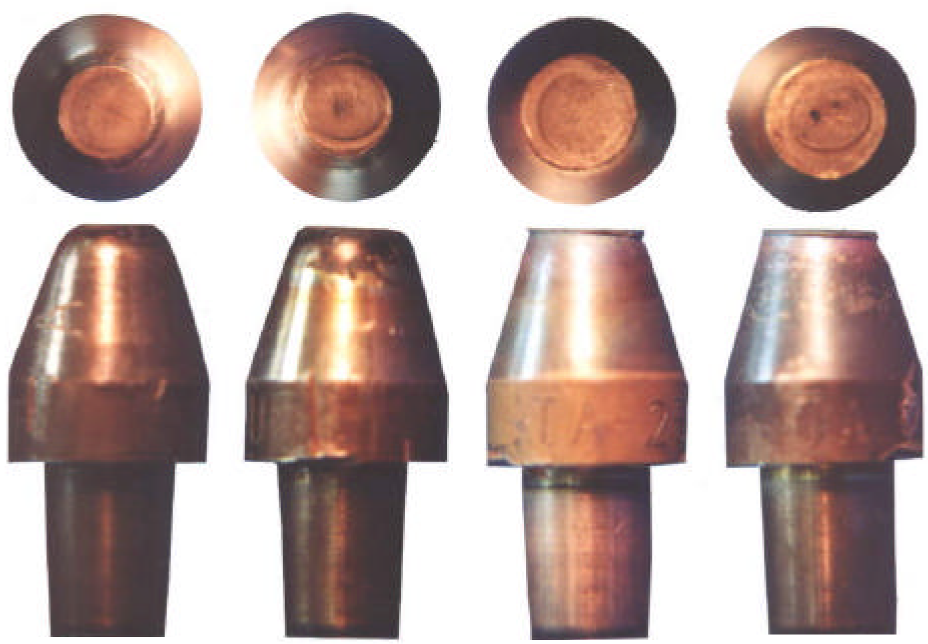
The two higher temperature runs started to increase in diameter at weld 750 and continued in an almost straight line through weld 8,000. At the end of these two runs, the electrode diameter had increased by an average of 42.4%

On the two lower temperature runs, electrode contact diameter remained constant through weld 6,000 with the final diameter increase averaging 14.4%. The effect of water flow on the two lower temperature runs was negligible at .8%. However the effect of lower water flow on the higher temperature runs showed a measurable difference from weld 4,500 through 8,000 with he final value at 4.4%.

APPENDIX E through H also track when the electrodes started to stick after each weld. On the two lower temperature runs, no sticking was noted through weld 8,000. On the two higher temperature runs, the advent of sticking occurred at weld 5,750 to 6,250 and continued through the end of the runs.

These tables also gives weld surface condition. On the two lower temperature tests, the weld nugget remained clean and symmetrical for each of the 8,000 weld runs. The higher temperature runs started to show irregular shape patterns on the exterior of the welds at weld 2,000 (high flow) and 4,750 (low flow) and then an increase in nugget zone depth at weld 4,250. At the very end of both higher temperature runs, the nugget area was noticeably rough. This matched the pattern starting to form in the electrode face.

FIGURE 9: ELECTRODES AFTER 8,000 WELDS ON .050 CRS



The last area observed is shown in the ELECTRODE CONDITION columns of the four tables. This follows the physical appearance of the electrodes through each run. FIGURE 9 shows photographs of the electrodes after 8,000 welds. Electrodes used in the lower temperature tests are almost unchanged whereas the electrodes using higher temperature water have noticeable deformation and diameter change.

On the higher temperature runs, visual distortion of electrodes was observed at weld 2,750, visual mushrooming at weld 3,500, and discoloration of the electrode and shank at weld 5,000 for both water flow runs. There appeared to be no difference between the low and high water flow runs.

RESULTS ON .031 CRS G90 GALVANIZED

For this group of runs, a weld program was chosen that allows the galvanized coating to liquefy and be displaced from the exterior and interior nugget area prior to the start of WELD TIME. This program produced the best welding results by far over UPSLOPE or PULSATION sequences prior to data collection for this paper and was, therefore, chosen for these runs..

The sequence was: PREHEAT, COOL, WELD, HOLD.

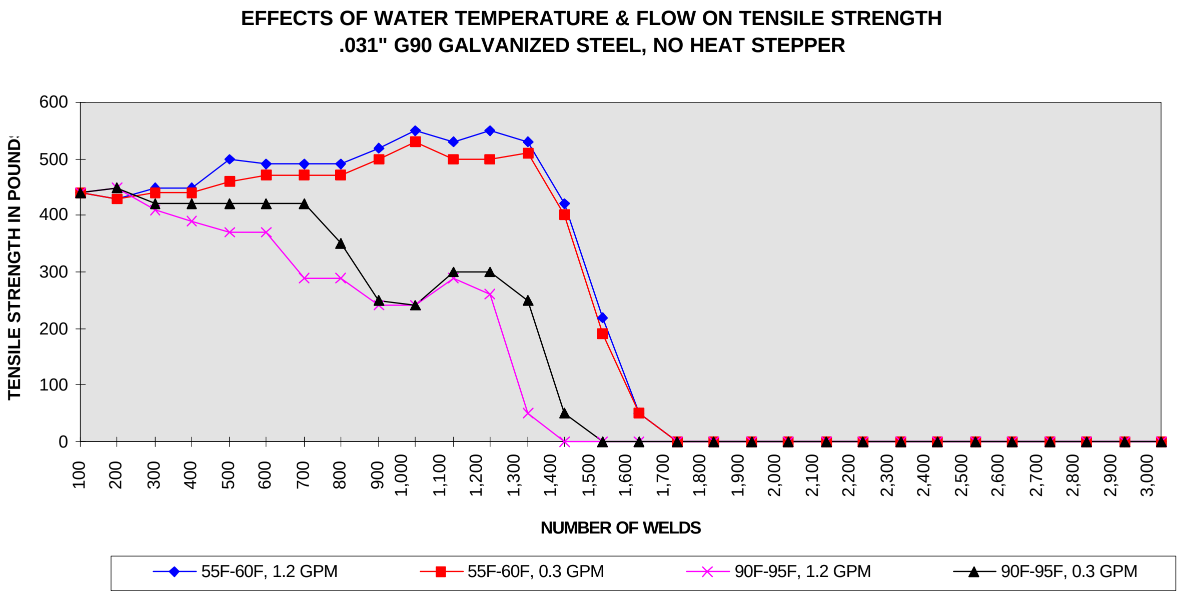
The welding control was set with the following parameters:

SQUEEZE TIME = 00 cycles (fires from transducer signal)
PREHEAT TIME = 08 cycles
PREHEAT CURRENT = 7,200 amps
DELAY AFTER PREHEAT = 5 cycles
WELD TIME = 10 cycles
WELD CURRENT =11,480
HOLD TIME = 03 cycles
ELECTRODE FORCE = 420 LB.

RUNS WITHOUT HEAT STEPPER

The first galvanized runs were made without a HEAT STEPPER function. The results on tensile are shown on GRAPH 7. The data can be found in APPENDIX I

GRAPH 7



through L.

Tensile values started to drop at about the 600 weld point for the two higher temperature water runs. These values continued to dropped rapidly and testing was discontinued after about 1,400 welds when no nugget was formed. The two tests run with lower temperature water increased until weld 1,200 and then started to drop sharply. These tests were discontinued at about weld 1,600 when no nugget was formed.

In both higher and lower water temperature runs, the difference between the 1.2 gpm and 0.3 gpm flows did not appear to have a significant effect on the tensile values.

Because the test was stopped well before the 3,000 weld point, no documentation was made of nugget diameter or electrode face changes.

RUNS WITH HEAT STEPPER

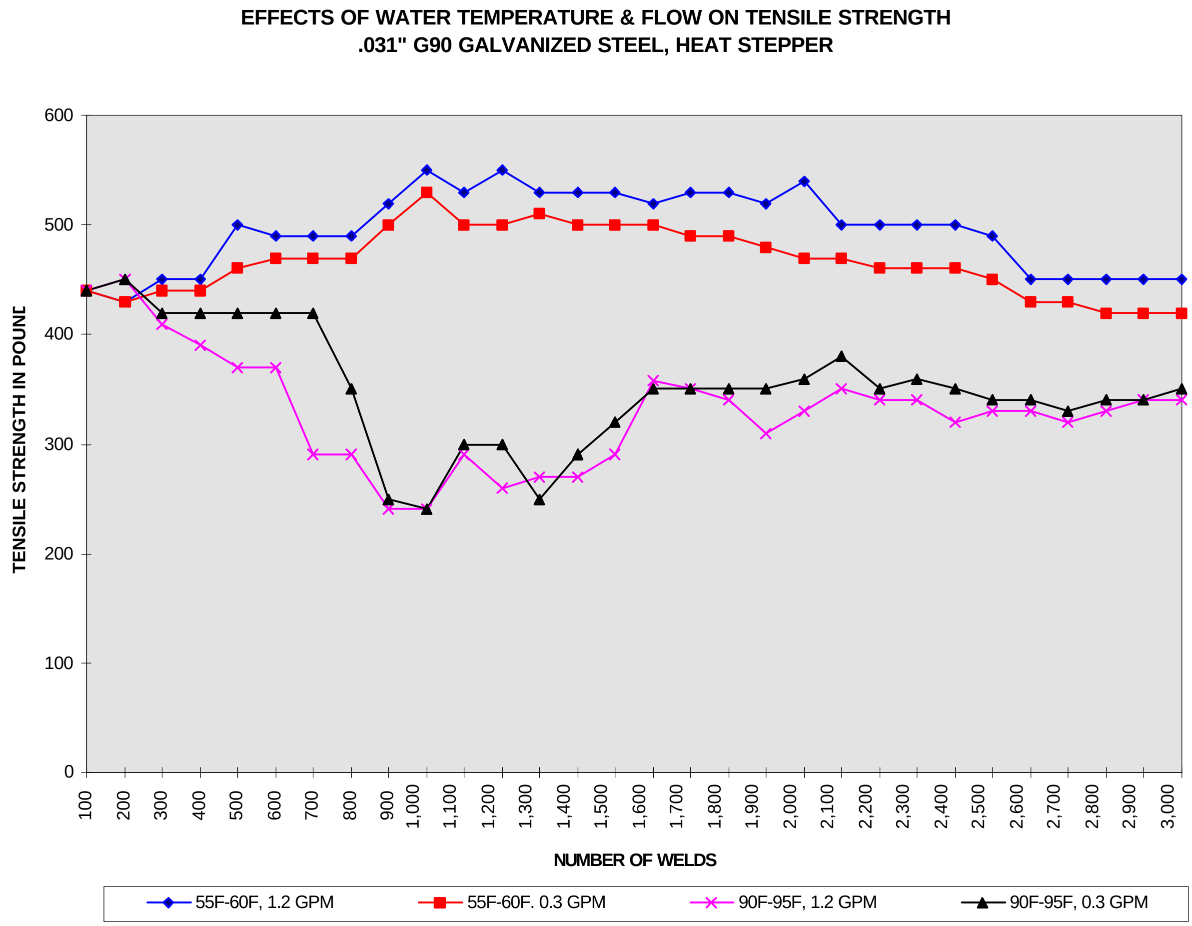
Four runs of 3,000 welds were now made using a computerized HEAT STEPPER CURVE in the welding control. The stepper increased the current to a maximum of 12,560 amps by weld 3,000.

GRAPH 8 shows the effect on TENSILE values with the four water conditions. Data for these graphs can be found in APPENDIX M through P.

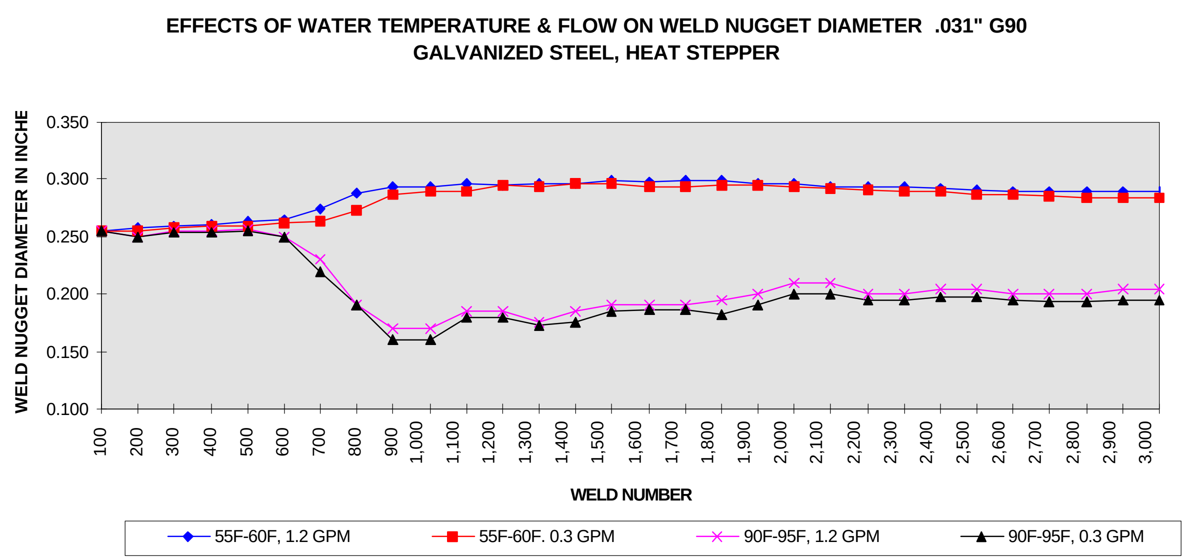
The two lower temperature runs increased in tensile about 10% as the effective electrode diameter increased , then remained stable through weld 3,000 with the heat stepper increases. At the end of 3,000 welds, tensile on the higher water flow run was 2.2% higher than the initial value, and for the lower water flow run had decreased 4.5%. Averaging the two, decrease of tensile was 1.2%.

On the two higher temperature runs, the tensile

GRAPH 8



GRAPH 9



started to decrease at the 750th. weld and was picked up by the heat stepper (same stepper pattern as with the lower temperature runs) continuing through weld 3,000 at an almost constant value. The final average tensile was 21.6% lower than the initial values.

By the end of 3,000 welds, there was no measurable difference in tensile for the higher temperature runs using different water flow rates. However on the lower temperature runs, the difference of water flow averaged a decrease in tensile of 6.7% (-4.5%-[+2.2%]).

An attempt was made at the end of one higher temperature run (without changing or dressing electrodes) to increase nugget tensile and diameter by artificially increasing the weld heat. Because electrode force was not changed, this resulted in major metal expulsion and only minor increase in both values. In addition, the electrodes dug extremely deep crater into the metal surface and exhibited major sticking.

GRAPH 9 follows the WELD NUGGET diameter. On the two runs with lower temperature, the diameter is constant until weld 700 when it rises and reasonably stabilizes through weld 3,000 where the nugget diameter has actually increased about 12% over the first nuggets. At weld 3,000, final nugget diameter averaged 12.4% larger than the initial nuggets. This was caused by the combination of a larger electrode diameter and the use of a heat stepper.

On the higher temperature runs, nugget diameter starts dropping at weld 700 and reaches a lower level around weld 900 with a tensile reduction of 33%. This rises slightly due to the heat stepper until weld 3,000 where the diameter averages a decrease of 21.6%. It should be noted that these welds are being made with a heat stepper that had been tuned for the lower temperature water group.

Lowering the water flow had a minimal effect on nugget diameter with a final value of 2.3% on the lower temperature run, and 3.9% on the higher temperature run.

GRAPH 10 tracks the ELECTRODE face diameter for each of the four water conditions. In observing the electrode face, it was noted that an outer lip of zinc forms which does not effect the nugget size or strength. This ring does, however, print on the galvanized coating of the metal around the nugget and effects the cosmetic appearance of the welding zone.

Electrode face dimension measurements were taken using the sharp edges of an electronic micrometer just under this extended zinc ring to produce more meaningful results.

Sectioning these electrodes showed that a fine layer of brass had formed on the outer face, and that the height of the electrode was being reduced by the transfer of copper during this alloy process (zinc + copper = brass) with a lesser effect from normal plastic flow of the copper. As can be seen in FIGURE 10, the electrodes do not classically mushroom in the copper area but rather appear to just have the top surface moved

GRAPH 10

EFFECTS OF WATER TEMPERATURE & FLOW ON ELECTRODE DIAMETER .031" G90 GALVANIZED STEEL HEAT STEPPER

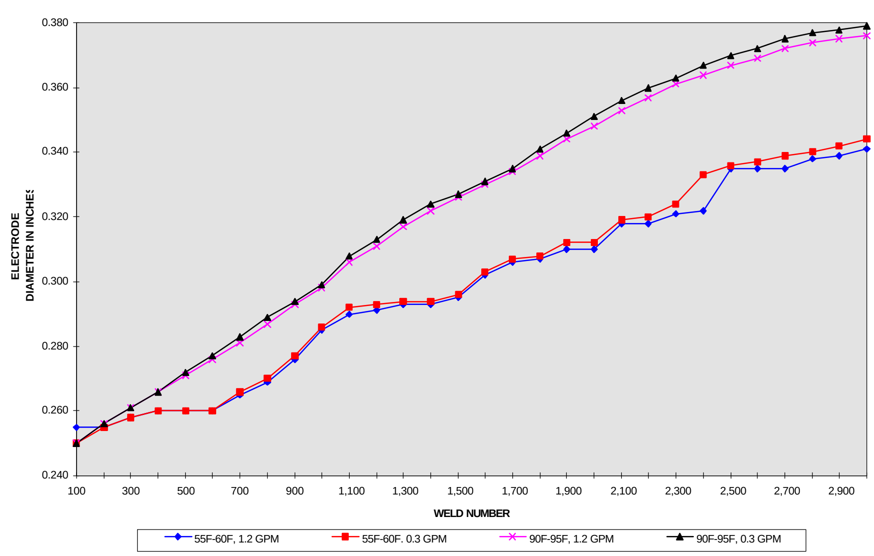
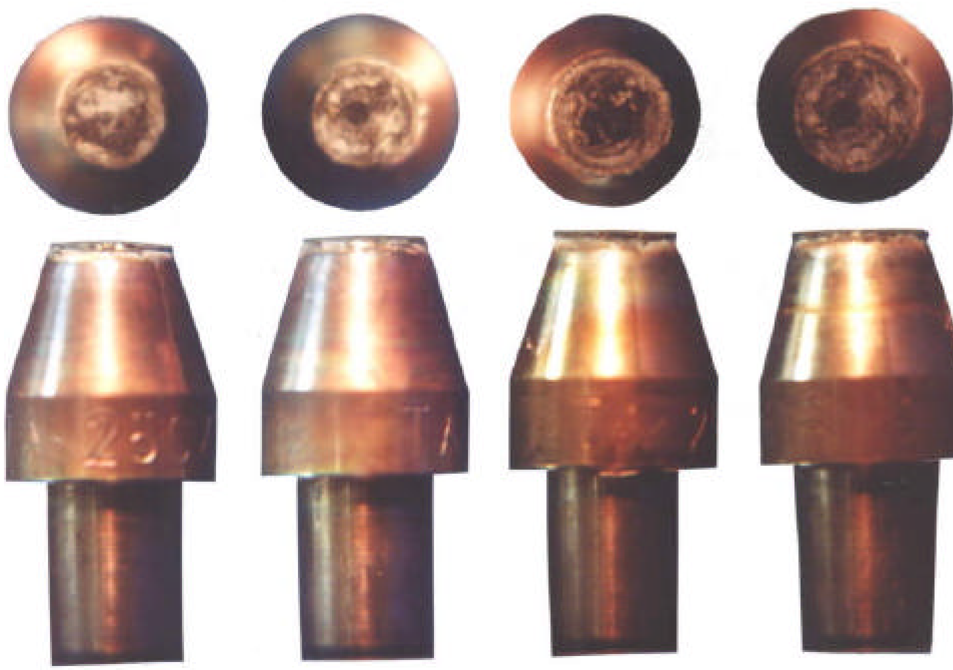


FIGURE 10: ELECTRODES AFTER 3,000 WELDS ON .031 G90



55°F - 60°F 1.2 GPM	55°F - 60°F 0.3 GPM	90°F - 95°F 1.2 GPM	90°F - 95°F 0.3 GPM

tion without rotating the steel.

These tables also give weld surface condition. Visual conditions for all runs was a poor indicator of weld tensile strength and nugget diameter. While the lower temperature runs remained visually cleaner longer, the difference was not great and became quite subjective. However the pattern still shows the trend of slight improvement with lower

towards the shank of the cap as copper is removed.

Both higher and lower temperature runs started to increase on an almost straight line manner through weld 3,000.

The two higher temperature runs started increased in diameter to an average of 50.9% by weld 3,000.

The two lower temperature runs grew an average of 35.7% by weld 3,000.

Decreasing water flow yielded an minor increase in electrode diameter of 3.9% on the higher temperature runs, and 1.2% on the higher temperature runs.

APPENDIX M through APPENDIX P also track when the electrodes started to stick after each weld. The advent of sticking started at weld 2,300-2400 on the two lower temperature runs. Sticking began at weld 1300-1400 on the higher temperature runs. It was also noted that by weld 2,700 on the two higher temperature runs, sticking was strong enough to prevent the part from being moved to the next weld loca-

FIGURE 11: EFFECT OF HIGH WATER TEMPERATURE ON CAP REMOVAL

55°F - 60°F 1.2 GPM	90°F - 95°F 1.2 GPM

temperature water for about 70% each run.

EFFECT ON ELECTRODE SHANK

Figure 11 shows a side result of testing. The cap and shank on the right shows the conditions reached at the end of an 8,000 weld run on .050" CRS with 1.2 gpm water at 90°F - 95°F. The cap has been fully pushed into the taper of the shank. It became impossible to remove the cap using any of the wedge type tools. Removal was only possible by either using locking pliers with deep teeth or by removing the shank and inserting a drift pin from the other end. In both cases, both surface and sometimes dimensional damage was done to the shank.

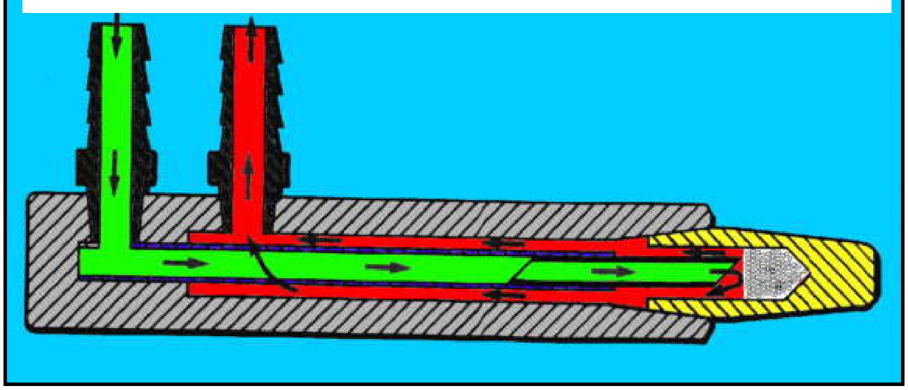
The cap and shank on the left was photographed after an 8,000 weld run on .050 CRS with 1.2 gpm water at 55°F - 60°F. The gap between the cap and the shank allowed easy removal without any damage to the shank.

Also notice that the exterior color of the copper on the right side shank and cap is darker and mottled when compared to the lower temperature set to the left.

WELDER COMPONENT TEMPERATURE

Another observation was made of the water cooled electrode holders and welder arms. On all runs using lower temperature water, all of these components remained at or below room temperature.

FIGURE 12: RETRACTED WATER TUBE ELIMINATES CONVECTIVE HEAT REMOVAL



On all higher temperature runs, the surface temperatures were often high enough to be painful to the touch.

TEST WITH SLIDING WATER TUBE RETRACTED

The last group of tests for this paper were done to see the effect of moving the internal sliding water cooling tube back from the interior of the electrode. To do this, the spring loaded electrode holders were replaced with conventional holders that allowed the sliding water tube to be positioned 1" back from the bottom of the electrode cap as shown in FIGURE 10. Water was set at 1.2gpm and 55°F - 60°F.

Since the water tube is no longer set fully to the bottom of the electrode as shown in FIGURE 12, water finds an easier path directly back to the return of the holder. Water that has become trapped inside the electrode is now subjected to elevated temperatures that cause the water to boil and create steam (bubbles in the diagram).

This steam is a very poor thermal conductor. Therefore thermal removal by convection on the inside of the electrode is reduced to a minimum. Water flowing through an electrode holder with a retracted tube therefore only removes heat from the holder and leaves the electrode virtually the same as if no water flow were present.

The welding schedule used was:

SQUEEZE TIME = 00 cycles (fires from transducer signal)
WELD TIME = 12 cycles
WELD CURRENT =10,500
HOLD TIME = 03 cycles
ELECTRODE FORCE = 650 LB.

The results of 8,000 welds on .050 CRS is shown in GRAPH 11 with supporting data in APPENDIX Q. The second curve is the same material using a properly positioned sliding water tube with the same water conditions.

In this test, the electrode became discolored just after weld 1,000 and showed distinct mushrooming by weld 6,500. At the end of the test, the cap had pushed fully into the shank making removal impossible without damage to the cap and shank. The electrode holder, however, remained below room temperature for the complete run.

GRAPH 11

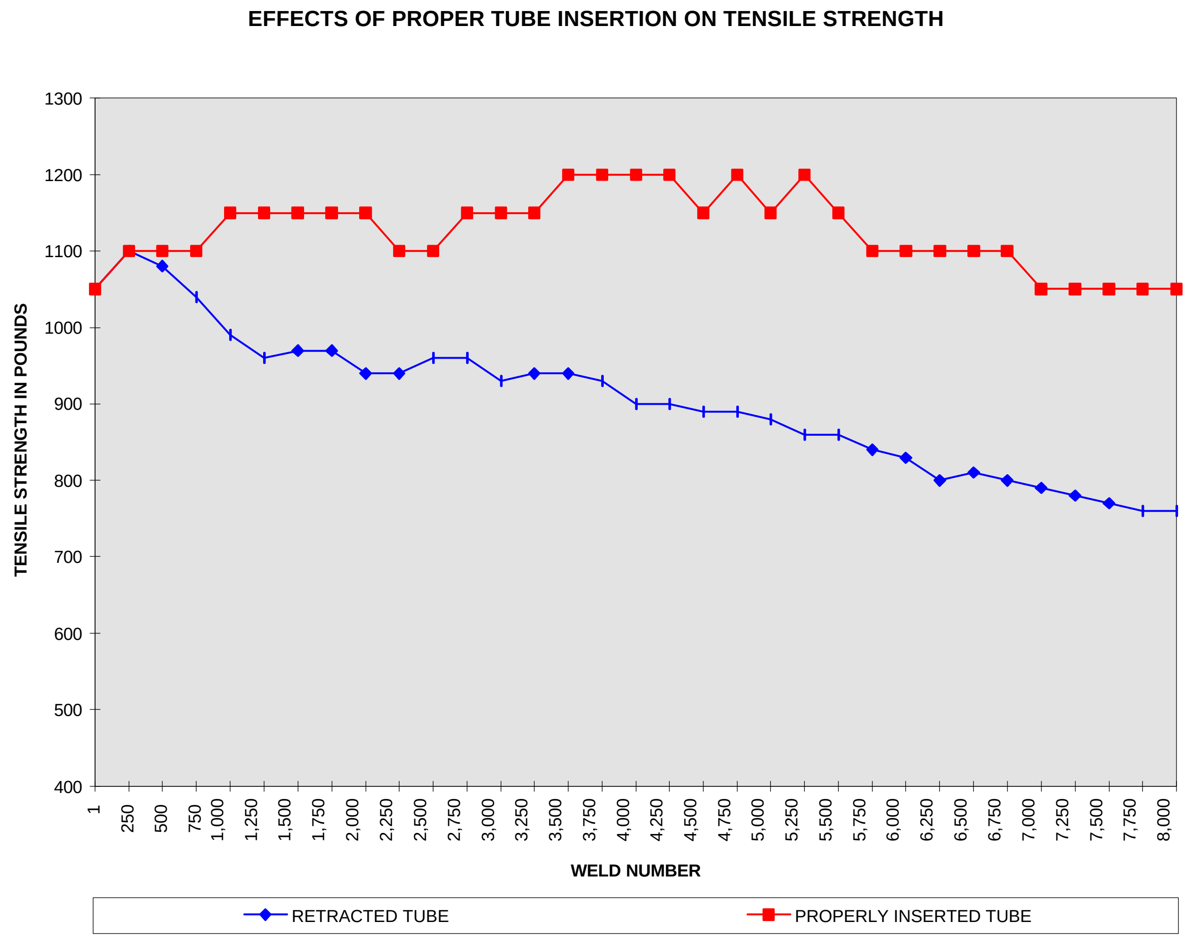
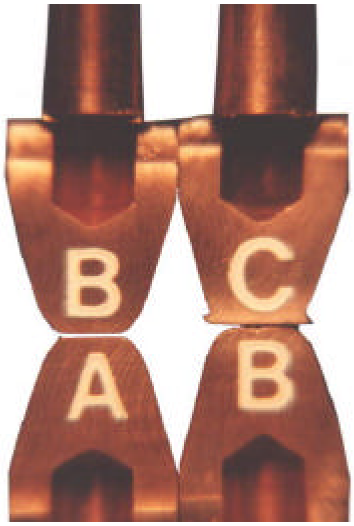


FIGURE 13: AFTER 8,000 WELDS ON .050 CRS



A = NEW ELECTRODE
B = PROPER TUBE INSERTION AFTER 8,000 WELDS
C = RETRACTED TUBE AFTER 8,000 WELDS

As shown in GRAPH 11, The weld TENSILE dropped starting at weld 1,000 in an almost straight line through weld 8,000. The tensile at the end of the run was 28% lower than at the start of the run.

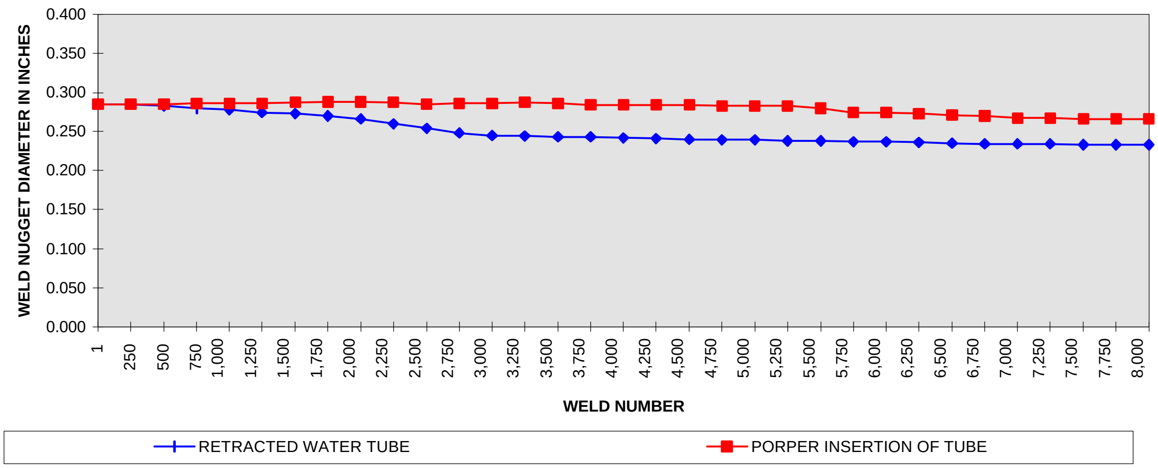
The weld NUGGET, as shown in GRAPH 12, decreased in diameter in an almost straight line finishing 22% smaller than at the beginning. The shape of the nugget was also irregular.

Observation of the ELECTRODE diameter, GRAPH 13, shows a rapid almost straight line increase ending 42% larger than the original face.
FIGURE 13 shows cross sectioned electrode caps for both runs. Electrode cap A is unused. Electrode cap B is a section of top and bottom electrodes after 8,000 welds with the spring loaded water tube. Electrode cap C was used for the retracted water tube run.

Note that the B electrodes have no visual difference

GRAPH 12

EFFECTS OF PROPER TUBE INSERTION ON WELD NUGGET DIAMETER



GRAPH 13

EFFECTS OF PROPER TUBE INSERTION ON ELECTRODE DIAMETER

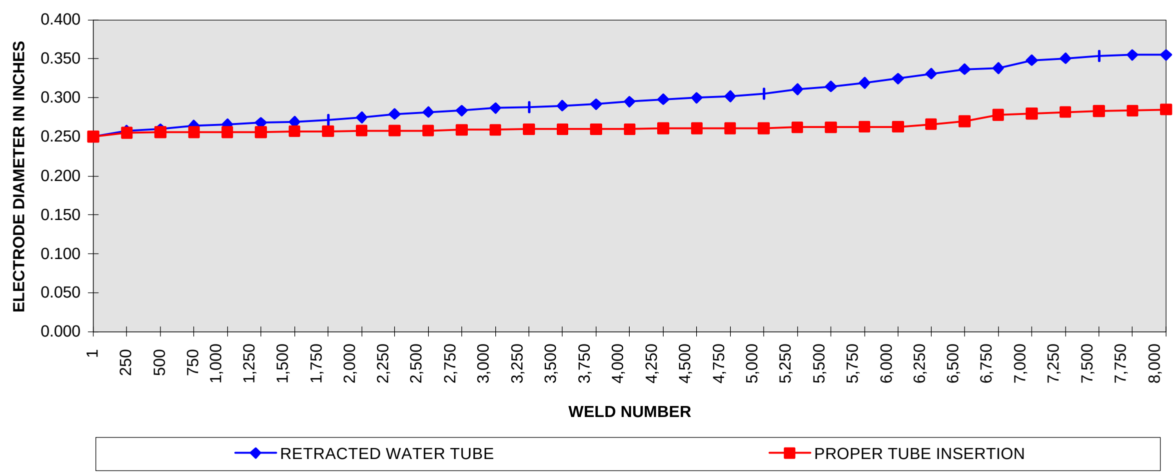


FIGURE 14

METAL	DECREASE PERCENT OF TENSILE*				DECREASE PERCENT OF NUGGET DIAMETER**				INCREASE PERCENT OF ELECTRODE FACE DIAMETER			
.029 CRS	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
.029 CRS	8.0	12.0	34.0	36.0	4.4	4.8	12.4	19.7	0.8	0.8	41.9	45.5
.050 CRS	0.0	4.8	23.8	28.6	6.6	6.6	15.0	17.0	14.0	14.8	40.0	44.4
.031 GALV.	**2.2**	4.5	22.7	22.7	**13.7**	**11.4**	19.6	23.5	33.7	37.6	50.4	51.6
.050 CRS* **	27.6	-	-	-	18.2	-	-	-	42.0	-	-	-

A = 55°F - 60°F, 1.2 GPM   C = 90°F - 95°F, 1.2 GPM
B = 55°F - 60°F, 0.3 GPM   D = 90°F - 95°F, 0.3 GP

* Values in **bold** are measured as an increased tensile value
** Values in **bold** are measured as an increase in nugget diameter
*** Run was made with the sliding water tube retracted 1”

from the unused A electrode. Electrode C shows an obvious plastic flow of the copper causing the major diameter change at the welding surface.

Some minor sticking was observed after weld 1,500 through the end of the run on the retracted tube group, but no sticking of any kind occurred with the properly positioned water tube set of welds.

COMPARING RESULTS

FIGURE 14 shows a comparison of differential test values for each water temperature and flow condition. Values were obtained using the following formula for each section:

$$\textbf{PERCENT CHANGE} = \frac{\textbf{FINAL VALUE - INITIAL VALUE}}{\textbf{INITIAL VALUE}}$$

CONCLUSIONS

By abstracting percentile changes in TENSILE, NUGGET DIAMETER, and ELECTRODE FACE DIAMETER as listed in FIGURE 14, the effect of increased water temperature verses decrease in water flow produces the following conclusions on the three material groups tested:

1. Raising of WATER TEMPERATURE from 55°F-60°F to 90°F-95°F produced a major effect on WELD TENSILE values over test runs:

a. Decreasing tensile an average of 25.0% on .029 CRS
b. Decreasing tensile an average of 23.8% on .050 CRS
c. Decreasing tensile an average of 21.6% on .031 G90

2. Reducing WATER FLOW from 1.2 gpm to 0.3 gpm had only a minor effect on WELD TENSILE over test runs:

a Decreasing tensile an average of 3.0% on .029 CRS
b Decreasing tensile an average of 4.8% on .050 CRS
c Decreasing tensile an average of 3.1% on .031 G90

3. Raising of WATER TEMPERATURE from 55°F-60°F to 90°F-95°F produced significant results on WELD NUGGET DIAMETER decreases over test runs:

a. Decreasing nugget diameter an average of 11.5% on .029 CRS
b. Decreasing nugget diameter an average of 9.4% on .050 CRS
c. Decreasing nugget diameter an average of 9.0% on .031 G90

4. Reducing WATER FLOW from 1.2 gpm to 0.3 gpm had only a minor effect on WELD NUGGET DIAMETER increases over test runs:

b. Decreasing nugget diameter an average of 3.9% on .029 CRS
c. Decreasing nugget diameter an average of 1.0% on .050 CRS
d. Decreasing nugget diameter an average of 3.1% on .031 G90

5. Raising of WATER TEMPERATURE from 55ºF-60°F to 90°F-95°F produced a major effect on ELECTRODE FACE DIAMETER increases over test runs:

b. Increasing electrode diameter an average of 42.8% on .029 CRS
c. Increasing electrode diameter an average of 27.8% on .050 CRS
d. Increasing electrode diameter an average of 15.4% on .031 G90

6. Reducing WATER FLOW from 1.2 gpm to 0.3 gpm had only a minor effect on final ELECTRODE FACE DIAMETER over test runs:

b. Increasing electrode diameter an average of 3.0% on .029 CRS
c. Increasing electrode diameter an average of 4.8% on .050 CRS
d. Increasing electrode diameter an average of 2.6% on .031 G90

7. Positioning the adjustable COOLING TUBE 1" back from the inside water hole of the electrode had major influence on tensile strength, weld nugget diameter, and electrode face diameter. Compared to a run with a properly positioned adjustable tube on .050 CRS (APPENDIX E to APPENDIX H), and operated at the same water conditions, this mechanical change over the 8,000 weld run:

a. Decreased tensile 27.6%
b. Decreased weld nugget diameter by 11.6%
c. Increased electrode face diameter by 28.0%

8. Raising of WATER TEMPERATURE from 55°F-60°F to 90°F-95°F caused the ELECTRODE CAP to be pushed fully down to the shank making removal impossible without damage to the shank. With water at the lower temperature, the electrode cap remained spaced from the shank allowing easy removal with a commercial cap removal tool.

9. Increase of water temperature promoted surface distortion of weld zone and electrode sticking in all materials tested.

10. Since electrode geometry and weld tensile on bare CRS showed only small changes at the end of the 8,000 weld runs using lower temperature water, there appears to be no reason to prevent 10,000 - 15,000 or more welds to be made without any dressing of electrodes or deterioration of the weld being produced.

11. Observing that very little change is imparted on electrodes operated with water at 55°F - 60°F and 1.2 gpm, there appears to be no reason to lower water temperature further or to raise water flow.

12. No direct test data was gathered to measure potential electrode life and required electrode dressing schedule. However observation that the electrode diameter increased an average of 28.5% during the higher temperature water and retracted water tube runs strongly indicates that these conditions would require greater frequency of dressing, more time for dressing, and diminish the quantity of welds that could be produced on an individual electrode. At follows that increased frequency of dressing and electrode replacement would reduce the potential welds/hour possible from a welding system. This becomes even more significant on multiple electrode welding stations.

REFERENCES

1. Welding Handbook, AWS, 8th. edition, book 2, page 641
2. Resistance Welding Manual, RWMA, 4th. edition, page 18-8
3. SME Resistance Welding Proceedings, August 30-31, 1995, How Geometry of Electrodes Effects Weld Development, Michael S. Simmons, Tuffaloy Products, Inc.
4. Model 8050, Unitrol Electronics, Inc.
5. Model RMB-85, Dwyer Instruments, Inc.
6. Model 321-0220, Tuffaloy Products, Inc.

APPENDIX A
WATER TEMPERATURE = 90°F – 95°F, WATER FLOW = 1.2 GPM
.029" - .031" 1010 COLD ROLLED STEEL

NO.	TENSILE	EL. COND.	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
1	500	-	0.236	NO	A	0.249
250	480	A	0.236	NO	A	0.249
500	430	A	0.236	NO	A	0.249
750	440	A	0.238	NO	A	0.249
1,000	390	A	0.238	NO	A	0.248
1,250	400	A	0.238	NO	A	0.248
1,500	400	A	0.238	NO	A	0.246
1,750	400	A	0.238	NO	A	0.245
2,000	400	A	0.240	NO	A	0.245
2,250	420	A	0.240	NO	A	0.244
2,500	400	A	0.242	NO	B	0.243
2,750	370	B	0.245	NO	B	0.240
3,000	380	B	0.248	NO	B	0.238
3,250	400	B	0.253	NO	B	0.238
3,500	400	C,E	0.257	NO	B	0.238
3,750	410	C,E	0.264	NO	B	0.237
4,000	400	C,E	0.269	NO	B	0.236
4,250	400	C,E	0.273	NO	B,C	0.235
4,500	380	C,E	0.277	NO	B,C	0.233
4,750	380	C,E	0.281	NO	B,C	0.232
5,000	370	D,E	0.286	NO	B,C	0.232
5,250	370	D,E	0.290	NO	B,C	0.232
5,500	370	D,E	0.295	YES	B,C	0.231
5,750	360	D,E	0.297	YES	B,C	0.230
6,000	360	D,E	0.305	YES	B,C	0.228
6,250	350	D,E	0.309	YES	B,C	0.226
6,500	350	D,E	0.313	YES	B,C	0.223
6,750	350	D,E	0.319	YES	B,C	0.220
7,000	350	D,E	0.323	YES	B,C	0.220
7,250	350	D,E	0.329	YES	B,C	0.219
7,500	340	D,E	0.330	YES	B,C	0.219
7,750	340	D,E	0.332	YES	B,C,E	0.218
8,000	330	D,E	0.335	YES	B,C,E	0.218

APPENDIX B
WATER TEMPERATURE = 90°F – 95°F, WATER FLOW = 0.3 GPM
.029" - .031" 1010 COLD ROLLED STEEL

NO.	TENSILE	EL. COND.	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
1	500	-	0.236	NO	A	0.249
250	480	A	0.236	NO	A	0.249
500	430	A	0.236	NO	A	0.249
750	440	A	0.238	NO	A	0.249
1,000	380	A	0.240	NO	A	0.248
1,250	390	A	0.245	NO	A	0.248
1,500	390	A	0.248	NO	A	0.246
1,750	390	A	0.248	NO	A	0.245
2,000	390	A	0.248	NO	A	0.245
2,250	410	A	0.253	NO	A	0.244
2,500	400	A	0.257	NO	B	0.243
2,750	360	B	0.264	NO	B	0.240
3,000	360	B	0.269	NO	B	0.238
3,250	370	B	0.273	NO	B	0.236
3,500	390	C,E	0.277	NO	B	0.236
3,750	390	C,E	0.281	NO	B	0.234
4,000	400	C,E	0.286	NO	B	0.233
4,250	400	C,E	0.290	NO	B,C	0.231
4,500	390	C,E	0.295	NO	B,C	0.227
4,750	370	C,E	0.297	NO	B,C	0.225
5,000	370	D,E	0.305	NO	B,C	0.225
5,250	370	D,E	0.309	NO	B,C	0.223
5,500	360	D,E	0.313	YES	B,C	0.222
5,750	360	D,E	0.319	YES	B,C	0.218
6,000	350	D,E	0.323	YES	B,C	0.214
6,250	350	D,E	0.329	YES	B,C	0.213
6,500	350	D,E	0.330	YES	B,C	0.212
6,750	350	D,E	0.332	YES	B,C	0.210
7,000	340	D,E	0.335	YES	B,C	0.210
7,250	330	D,E	0.337	YES	B,C	0.209
7,500	330	D,E	0.339	YES	B,C	0.205
7,750	320	D,E	0.341	YES	B,C,E	0.200
8,000	320	D,E	0.343	YES	B,C,E	0.200

APPENDIX C
WATER TEMPERATURE = 55°F – 60°F, WATER FLOW = 1.2 GPM
.029" - .031" 1010 COLD ROLLED STEEL

NO.	TENSILE	EL. COND.	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
1	500	-	0.236	NO	A	0.249
250	480	A	0.236	NO	A	0.249
500	470	A	0.236	NO	A	0.249
750	480	A	0.236	NO	A	0.249
1,000	470	A	0.236	NO	A	0.249
1,250	470	A	0.236	NO	A	0.249
1,500	460	A	0.236	NO	A	0.249
1,750	460	A	0.236	NO	A	0.249
2,000	460	A	0.236	NO	A	0.249
2,250	460	A	0.236	NO	A	0.249
2,500	460	A	0.236	NO	A	0.249
2,750	460	A	0.237	NO	A	0.249
3,000	460	A	0.237	NO	A	0.249
3,250	450	A	0.237	NO	A	0.249
3,500	450	A	0.237	NO	A	0.248
3,750	460	A	0.237	NO	A	0.248
4,000	460	A	0.237	NO	A	0.247
4,250	460	A	0.237	NO	A	0.247
4,500	460	A	0.237	NO	A	0.247
4,750	470	A	0.238	NO	A	0.246
5,000	470	A	0.238	NO	A	0.246
5,250	480	A	0.238	NO	A	0.245
5,500	480	A	0.238	NO	A	0.245
5,750	480	A	0.238	NO	A	0.245
6,000	480	A	0.238	NO	A	0.245
6,250	470	A	0.238	NO	A	0.244
6,500	470	A	0.238	NO	A	0.244
6,750	470	A	0.238	NO	A	0.244
7,000	470	A	0.238	NO	A	0.243
7,250	460	A	0.238	NO	A	0.243
7,500	460	A	0.238	NO	A	0.241
7,750	460	A	0.238	NO	A	0.239
8,000	460	A	0.238	NO	A	0.238

APPENDIX D
WATER TEMPERATURE = 55°F – 60°F, WATER FLOW = 0.3 GPM
.029" - .031" 1010 COLD ROLLED STEEL

NO.	TENSILE	EL. COND.	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
1	500	-	0.236	NO	A	0.249
250	480	A	0.236	NO	A	0.249
500	470	A	0.236	NO	A	0.249
750	480	A	0.236	NO	A	0.249
1,000	470	A	0.236	NO	A	0.249
1,250	470	A	0.236	NO	A	0.249
1,500	460	A	0.236	NO	A	0.249
1,750	460	A	0.237	NO	A	0.249
2,000	460	A	0.237	NO	A	0.249
2,250	460	A	0.238	NO	A	0.249
2,500	460	A	0.238	NO	A	0.249
2,750	450	A	0.239	NO	A	0.249
3,000	450	A	0.239	NO	A	0.249
3,250	450	A	0.239	NO	A	0.249
3,500	450	A	0.239	NO	A	0.248
3,750	450	A	0.239	NO	A	0.248
4,000	450	A	0.239	NO	A	0.247
4,250	450	A	0.239	NO	A	0.247
4,500	450	A	0.240	NO	A	0.247
4,750	460	A	0.240	NO	A	0.246
5,000	460	A	0.240	NO	A	0.246
5,250	460	A	0.240	NO	A	0.245
5,500	470	A	0.240	NO	A	0.245
5,750	470	A	0.240	NO	A	0.245
6,000	460	A	0.240	NO	A	0.245
6,250	460	A	0.240	NO	A	0.244
6,500	450	A	0.240	NO	A	0.243
6,750	450	A	0.240	NO	A	0.243
7,000	450	A	0.240	NO	A	0.241
7,250	450	A	0.240	NO	A	0.241
7,500	440	A	0.240	NO	A	0.239
7,750	440	A	0.240	NO	A	0.237
8,000	440	A	0.240	NO	A	0.237

ELECTRODE CONDITION		
A = Unchanged	C = Slight Mushrooming	E = Light Discoloration
B = Slightly Distorted	D = Mushrooming	

WELD CONDITION		
A = Clean, Symmetrical	C = Slight Depression	E = Roughness
B = Irregular Shape	D = Heavy Depression	

APPENDIX E
WATER TEMPERATURE = 55°F – 60°F, WATER FLOW = 1.2 GPM
.049" - .050" 1010 COLD ROLLED STEEL

NO.	TENSILE	EL. COND.	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
1	1050	-	0.250	NO	A	0.285
250	1100	A	0.255	NO	A	0.285
500	1100	A	0.256	NO	A	0.285
750	1100	A	0.256	NO	A	0.286
1,000	1150	A	0.256	NO	A	0.286
1,250	1150	A	0.256	NO	A	0.286
1,500	1150	A	0.257	NO	A	0.286
1,750	1150	A	0.257	NO	A	0.288
2,000	1150	A	0.258	NO	A	0.288
2,250	1100	A	0.258	NO	A	0.287
2,500	1100	A	0.258	NO	A	0.285
2,750	1150	A	0.259	NO	A	0.286
3,000	1150	A	0.259	NO	A	0.286
3,250	1150	A	0.260	NO	A	0.287
3,500	1200	A	0.260	NO	A	0.286
3,750	1200	A	0.260	NO	A	0.284
4,000	1200	A	0.260	NO	A	0.284
4,250	1200	A	0.261	NO	A	0.284
4,500	1150	A	0.261	NO	A	0284
4,750	1200	A	0.261	NO	A	0.283
5,000	1150	A	0.261	NO	A	0.283
5,250	1200	A	0.262	NO	A	0.283
5,500	1150	B	0.262	NO	A	0.280
5,750	1100	B	0.263	NO	A	0.274
6,000	1100	B	0.263	NO	A	0.274
6,250	1100	B	0.266	NO	A	0.273
6,500	1100	B	0.270	NO	A	0.271
6,750	1100	B	0.278	NO	A	0.270
7,000	1050	B	0.280	NO	A	0.267
7,250	1050	B	0.282	NO	A	0.267
7,500	1050	B	0.283	NO	A	0.266
7,750	1050	B	0.284	NO	A	0.266
8,000	1050	B	0.285	NO	A	0.266

APPENDIX F
WATER TEMPERATURE = 55°F – 60°F, WATER FLOW = 0.3 GPM
.049" - .050" 1010 COLD ROLLED STEEL

NO.	TENSILE	EL. COND.	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
1	1050	-	0.250	NO	A	0.285
250	1100	A	0.255	NO	A	0.285
500	1100	A	.0256	NO	A	0.285
750	1100	A	0.256	NO	A	0.286
1,000	1100	A	0.256	NO	A	0.286
1,250	1150	A	0.256	NO	A	0.285
1,500	1130	A	0.257	NO	A	0.286
1,750	1130	A	0.258	NO	A	0.287
2,000	1130	A	0.258	NO	A	0.287
2,250	1050	A	0.258	NO	A	0.287
2,500	1050	A	0.259	NO	A	0.285
2,750	1050	A	0.259	NO	A	0.286
3,000	1100	A	0.260	NO	A	0.286
3,250	1100	A	0.260	NO	A	0.286
3,500	1150	A	0.260	NO	A	0.285
3,750	1150	A	0.260	NO	A	0.283
4,000	1150	A	0.261	NO	A	0.283
4,250	1100	A	0.261	NO	A	0.282
4,500	1100	A	0.261	NO	A	0282
4,750	1150	A	0.261	NO	A	0.281
5,000	1100	B	0.262	NO	A	0.281
5,250	1100	B	0.263	NO	A	0.280
5,500	1050	B	0.264	NO	A	0.277
5,750	1050	B	0.265	NO	A	0.270
6,000	1000	B	0.268	NO	A	0.270
6,250	1000	B	0.272	NO	A	0.268
6,500	1000	B	0.280	NO	A	0.265
6,750	1050	B	0.283	NO	A	0.263
7,000	1000	B	0.285	NO	A	0.263
7,250	1000	B	0.286	NO	A	0.262
7,500	1000	B	0.287	NO	A	0.262
7,750	1000	B	0.287	NO	A	0.261
8,000	1000	B	0.287	NO	A	0.261

APPENDIX G
WATER TEMPERATURE = 90°F – 95°F, WATER FLOW = 1.2 GPM
.049" - .050" 1010 COLD ROLLED STEEL

NO.	TENSILE	EL. COND.	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
1	1050	-	0.250	NO	A	0.285
250	1100	A	0.258	NO	A	0.285
500	1080	A	0.260	NO	A	0.283
750	1050	A	0.263	NO	A	0.281
1,000	1000	A	0.265	NO	A	0.279
1,250	970	A	0.267	NO	A	0.276
1,500	990	A	0.268	NO	A	0.275
1,750	1000	A	0.270	NO	A	0.273
2,000	950	B	0.273	NO	A	0.269
2,250	920	B	0.277	NO	A	0.264
2,500	1000	B	0.280	NO	A	0.258
2,750	1000	B	0.282	NO	A	0.252
3,000	950	B	0.285	NO	B	0.250
3,250	950	B	0.286	NO	B	0.249
3,500	970	B	0.288	NO	B	0.248
3,750	950	B	0.290	NO	B	0.248
4,000	920	B	0.293	NO	B	0.247
4,250	900	B	0.295	NO	B	0.246
4,500	950	B	0.296	NO	B	0.246
4,750	900	B	0.298	NO	B,C	0.245
5,000	900	B	0.301	NO	B,C	0.245
5,250	900	B	0.306	NO	B,C	0.244
5,500	780	B	0.310	NO	B,C	0.244
5,750	870	B	0.314	NO	B,C	0.243
6,000	850	B	0.320	NO	B,C	0.243
6,250	820	B	0.326	YES	B,C	0.243
6,500	850	B	0.332	YES	B,C	0.242
6,750	850	B	0.338	YES	B,C	0.241
7,000	820	C	0.343	YES	B,C	0.241
7,250	800	C	0.346	YES	B,C	0.241
7,500	800	C	0.350	YES	B,C	0.240
7,750	800	C	0.350	YES	B,C	0.240
8,000	800	C	0.350	YES	B,C	0.240

APPENDIX H
WATER TEMPERATURE = 90°F – 95°F, WATER FLOW = 0.3 GPM
.049" - .050" 1010 COLD ROLLED STEEL

NO.	TENSILE	EL. COND.	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
1	1050	-	0.250	NO	A	0.285
250	1100	A	0.258	NO	A	0.285
500	1080	A	0.262	NO	A	0.283
750	1040	A	0.265	NO	A	0.280
1,000	1100	A	0.268	NO	A	0.278
1,250	980	A	0.269	NO	A	0.278
1,500	950	A	0.273	NO	A	0.275
1,750	950	A	0.277	NO	A	0.272
2,000	950	A	0.279	NO	A	0.268
2,250	920	A	0.282	NO	A	0.264
2,500	900	A	0.284	NO	B,C	0.257
2,750	950	A	0.285	NO	B,C	0.250
3,000	950	A	0.289	NO	B,C	0.247
3,250	920	A	0.292	NO	B,C	0.245
3,500	900	A	0.294	NO	B,C	0.244
3,750	900	A	0.297	NO	B,C	0.243
4,000	900	A	0.300	NO	B,C	0.243
4,250	900	A	0.305	NO	B,C	0.243
4,500	870	A	0.307	NO	B,C	0.242
4,750	870	A	0.310	NO	B,C	0.242
5,000	900	B	0.314	NO	B,C	0.242
5,250	850	B	0.318	NO	B,C	0.241
5,500	850	B	0.325	NO	B,C	0.241
5,750	800	B	0.330	YES	B,C	0.239
6,000	800	B	0.336	YES	B,C	0.239
6,250	820	B	0.341	YES	B,C	0.239
6,500	800	B	0.347	YES	B,C	0.239
6,750	780	C	0.353	YES	B,C	0.238
7,000	770	C	0.357	YES	B,C	0.238
7,250	750	C,D	0.359	YES	B,C	0.237
7,500	750	C,D	0.361	YES	B,C	0.236
7,750	760	C,D	0.361	YES	B,C,E	0.236
8,000	750	C,D	0.361	YES	B,C,E	0.236

ELECTRODE CONDITION

A = Unchanged	C = Slight Mushrooming	E = Light Discoloration
B = Slightly Distorted	D = Mushrooming	

WELD CONDITION

A = Clean, Symmetrical	C = Slight Depression	E = Roughness
B = Irregular Shape	D = Heavy Depression	

APPENDIX I WATER TEMPERATURE = 55°F – 60°F WATER FLOW = 1.2 GPM .031" G90 GALVANIZED STEEL, NO HEAT STEPPER	
NO.	TENSILE STRENGTH
100	440
200	430
300	450
400	450
500	500
600	490
700	490
800	490
900	520
1,000	550
1,100	530
1,200	550
1,300	530
1,400	420
1,500	220
1,600	50
1,700	0
1,800	0
1,900	0
2,000	0
2,100	0
2,200	0
2,300	0
2,400	0
2,500	0
2,600	0
2,700	0
2,800	0
2,900	0
3,000	0

APPENDIX J WATER TEMPERATURE = 55°F – 60°F WATER FLOW = 0.3 GPM .031" G90 GALVANIZED STEEL, NO HEAT STEPPER	
NO.	TENSILE STRENGTH
100	440
200	430
300	440
400	440
500	460
600	470
700	470
800	470
900	500
1,000	530
1,100	500
1,200	500
1,300	510
1,400	400
1,500	190
1,600	50
1,700	0
1,800	0
1,900	0
2,000	0
2,100	0
2,200	0
2,300	0
2,400	0
2,500	0
2,600	0
2,700	0
2,800	0
2,900	0
3,000	0

APPENDIX K WATER TEMPERATURE = 90°F – 95°F WATER FLOW = 1.2 GPM .031" G90 GALVANIZED STEEL, NO HEAT STEPPER	
NO.	TENSILE STRENGTH
100	440
200	450
300	410
400	390
500	370
600	370
700	290
800	290
900	240
1,000	240
1,100	290
1,200	260
1,300	50
1,400	0
1,500	0
1,600	0
1,700	0
1,800	0
1,900	0
2,000	0
2,100	0
2,200	0
2,300	0
2,400	0
2,500	0
2,600	0
2,700	0
2,800	0
2,900	0
3,000	0

APPENDIX L WATER TEMPERATURE = 90°F – 95°F WATER FLOW = 0.3 GPM .031" G90 GALVANIZED STEEL, NO HEAT STEPPER	
NO.	TENSILE STRENGTH
100	440
200	450
300	420
400	420
500	420
600	420
700	420
800	350
900	250
1,000	240
1,100	300
1,200	300
1,300	250
1,400	50
1,500	0
1,600	0
1,700	0
1,800	0
1,900	0
2,000	0
2,100	0
2,200	0
2,300	0
2,400	0
2,500	0
2,600	0
2,700	0
2,800	0
2,900	0
3,000	0

APPENDIX Q WATER TEMPERATURE = 55°F – 60°F, WATER FLOW = 1.2 GPM SHORTENED WATER TUBE INSERTION .049" - .050 COLD ROLLED STEEL					
NO.	TENSILE	ELECTRODE COND.	ELECT. DIA.	STICKING	NUGGET DIA.
1	1050	-	0.250	NO	0.285
250	1100	A	0.258	NO	0.285
500	1080	A	0.260	NO	0.283
750	1040	A	0.264	NO	0.280
1,000	990	A	0.266	NO	0.278
1,250	960	B	0.268	NO	0.274
1,500	970	B	0.269	NO	0.273
1,750	970	B	0.272	NO	0.270
2,000	940	B	0.275	NO	0.266
2,250	940	B	0.279	NO	0.260
2,500	960	B	0.282	NO	0.254
2,750	960	B	0.284	NO	0.248
3,000	930	B	0.287	NO	0.245
3,250	940	B	0.288	NO	0.244
3,500	940	B	0.290	NO	0.243
3,750	930	B	0.292	NO	0.243
4,000	900	B	0.295	NO	0.242
4,250	900	B	0.298	NO	0.241
4,500	890	B	0.300	NO	0.240
4,750	890	B	0.302	NO	0.239
5,000	880	B	0.305	NO	0.239
5,250	860	B	0.311	NO	0.238
5,500	860	B	0.315	YES	0.238
5,750	840	B	0.319	YES	0.237
6,000	830	B	0.325	YES	0.237
6,250	800	B	0.331	YES	0.236
6,500	810	C	0.337	YES	0.235
6,750	800	C	0.338	YES	0.234
7,000	790	C	0.348	YES	0.234
7,250	780	C	0.351	YES	0.234
7,500	770	C	0.354	YES	0.233
7,750	760	C	0.355	YES	0.233
8,000	760	C	0.355	YES	0.233

ELECTRODE	A = Unchanged	B = Slight Mushroom-ing	C = Mushrooming

APPENDIX M WATER TEMPERATURE = 55°F – 60°F, WATER FLOW = 1.2 GPM .031" G90 GALVANIZED STEEL, WITH HEAT STEPPER					
NO.	TENSILE	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
100	440	0.255	NO	A	0.255
200	430	0.255	NO	A,C	0.258
300	450	0.258	NO	A,C	0.260
400	450	0.260	NO	A,C	0.261
500	500	0.260	NO	A,C	0.263
600	490	0.260	NO	A,C	0.265
700	490	0.265	NO	A,C	0.275
800	490	0.269	NO	A,C	0.288
900	520	0.276	NO	A,C	0.293
1,000	550	0.285	NO	A,C	0.293
1,100	530	0.290	NO	B,C	0.296
1,200	550	0.291	NO	B,C	0.295
1,300	530	0.293	NO	B,C	0.297
1,400	530	0.293	NO	B,C	0.297
1,500	530	0.295	NO	B	0.299
1,600	520	0.302	NO	B	0.298
1,700	530	0.306	NO	B	0.299
1,800	530	0.307	NO	B	0.299
1,900	520	0.310	NO	B,D	0.296
2,000	540	0.310	NO	B,D	0.296
2,100	500	0.318	NO	B,D	0.294
2,200	500	0.318	NO	B,D	0.294
2,300	500	0.321	NO	B,D	0.294
2,400	500	0.322	YES	B,D	0.292
2,500	490	0.335	YES	B,D	0.291
2,600	450	0.335	YES	B,D	0.290
2,700	450	0.335	YES	B,D	0.290
2,800	450	0.338	YES	B,D	0.290
2,900	450	0.339	YES	B,D	0.290
3,000	450	0.341	YES	B,D	0.290

APPENDIX N WATER TEMPERATURE = 55°F – 60°F, WATER FLOW = 0.3 GPM .031" G90 GALVANIZED STEEL, WITH HEAT STEPPER					
NO.	TENSILE	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
100	440	0.250	NO	A	0.255
200	430	0.255	NO	A,C	0.255
300	440	0.258	NO	A,C	0.258
400	440	0.260	NO	A,C	0.260
500	460	0.260	NO	A,C	0.260
600	470	0.260	NO	A,C	0.262
700	470	0.266	NO	A,C	0.263
800	470	0.270	NO	A,C	0.273
900	500	0.277	NO	A,C	0.287
1,000	530	0.286	NO	B,C	0.290
1,100	500	0.292	NO	B,C	0.290
1,200	500	0.293	NO	B,C	0.295
1,300	510	0.294	NO	B,C	0.294
1,400	500	0.294	NO	B,C	0.296
1,500	500	0.296	NO	B,C	0.296
1,600	500	0.303	NO	B	0.293
1,700	490	0.307	NO	B	0.293
1,800	490	0.308	NO	B,D	0.295
1,900	480	0.312	NO	B,D	0.295
2,000	470	0.312	NO	B,D	0.294
2,100	470	0.319	NO	B,D	0.292
2,200	460	0.320	NO	B,D	0.291
2,300	460	0.324	YES	B,D	0.290
2,400	460	0.333	YES	B,D	0.290
2,500	450	0.336	YES	B,D	0.287
2,600	430	0.337	YES	B,D	0.287
2,700	430	0.339	YES	B,D	0.285
2,800	420	0.340	YES	B,D	0.284
2,900	420	0.342	YES	B,D	0.284
3,000	420	0.344	YES	B,D	0.284

APPENDIX O WATER TEMPERATURE = 90°F – 95°F, WATER FLOW = 1.2 GPM .031" G90 GALVANIZED STEEL, WITH HEAT STEPPER					
NO.	TENSILE	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
100	440	0.250	NO	A	0.255
200	450	0.256	NO	A,C	0.250
300	410	0.261	NO	A,C	0.255
400	390	0.266	NO	A,C	0.255
500	370	0.271	NO	A,C	0.257
600	370	0.276	NO	A,C	0.250
700	290	0.281	NO	B,C	0.230
800	290	0.287	NO	B,C	0.190
900	240	0.293	NO	B,C	0.170
1,000	240	0.298	NO	B,C	0.170
1,100	290	0.306	NO	B,C	0.185
1,200	260	0.311	NO	B,C	0.185
1,300	270	0.317	YES	B,D	0.175
1,400	270	0.322	YES	B,D	0.185
1,500	290	0.326	YES	B,D	0.190
1,600	358	0.330	YES	B,D	0.190
1,700	350	0.334	YES	B,D	0.190
1,800	340	0.339	YES	B,D	0.195
1,900	310	0.344	YES	B,D	0.200
2,000	330	0.348	YES	B,D	0.210
2,100	350	0.353	YES	B,D	0.210
2,200	340	0.357	YES	B,D	0.200
2,300	340	0.361	YES	B,D	0.200
2,400	320	0.364	YES	B,D	0.205
2,500	330	0.367	YES	B,D	0.205
2,600	330	0.369	YES	B,D	0.200
2,700	320	0.372	YES	B,D	0.200
2,800	330	0.374	YES	B,D	0.200
2,900	340	0.375	YES	B,D	0.205
3,000	340	0.376	YES	B,D	0.205

APPENDIX P WATER TEMPERATURE = 90°F – 95°F, WATER FLOW = 0.3 GPM .031" G90 GALVANIZED STEEL, WITH HEAT STEPPER					
NO.	TENSILE	EL. DIA.	STICKING	WELD COND.	NUGGET DIA.
100	440	0.250	NO	A	0.255
200	450	0.256	NO	A,C	0.250
300	420	0.261	NO	A,C	0.254
400	420	0.266	NO	A,C	0.254
500	420	0.272	NO	A,C	0.255
600	420	0.277	NO	A,C	0.250
700	420	0.283	NO	B,C	0.220
800	350	0.289	NO	B,C	0.190
900	250	0.294	NO	B,C	0.160
1,000	240	0.299	NO	B,C	0.160
1,100	300	0.308	NO	B,C	0.180
1,200	300	0.313	NO	B,C	0.180
1,300	250	0.319	YES	B,D	0.173
1,400	290	0.324	YES	B,D	0.175
1,500	320	0.327	YES	B,D	0.185
1,600	350	0.331	YES	B,D	0.186
1,700	350	0.335	YES	B,D	0.186
1,800	350	0.341	YES	B,D	0.183
1,900	350	0.346	YES	B,D	0.191
2,000	360	0.351	YES	B,D	0.200
2,100	380	0.356	YES	B,D	0.200
2,200	350	0.360	YES	B,D	0.195
2,300	360	0.363	YES	B,D	0.195
2,400	350	0.367	YES	B,D	0.198
2,500	340	0.370	YES	B,D	0.198
2,600	340	0.372	YES	B,D	0.195
2,700	330	0.375	YES	B,D	0.194
2,800	340	0.377	YES	B,D	0.194
2,900	340	0.378	YES	B,D	0.195
3,000	350	0.379	YES	B,D	0.195

WELD CONDITION	
A = Symmetrical Shape	C = Brass Pickup
B = Irregular Shape	D = Depression