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EWI Project No. 40900CSP

Operating Procedures for Conducting the A/SP DOE of Coated Steels

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Submitted to:

Auto/Steel Partnership
Southfield, Michigan

Operating Procedures

for

EWI Project No. 40900CSP

on

The A/SP's DOE of Coated Steels

to

Auto/Steel Partnership
Southfield, Michigan

July 30, 1999

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1.0 Background

1.1 Purpose of the Document

As part of the effort to promote the usage of steel in the production of automobiles and to reduce the cost of manufacturing, the Auto/Steel Partnership (A/SP) is conducting a program to identify factors which have the greatest influence on the variance of weld size/shape during a standard electrode life test. Identification of these factors will be accomplished through standard statistical analysis of design-of-experiment (DOE) test results, and through the development of a neural network model of the process. The primary objective of this effort is to (at a minimum) double the achievable electrode life. This increase in electrode life is believed to be obtainable by providing data that increases the confidence that a quality resistance spot weld is being produced when operating at reduced current levels (i.e., current levels just below expulsion). This program is targeted at generating information which will allow subsequent evaluations of tip dressing schedules, stepper schedules, weldgun arm rigidity, machine age, etc. As such, a secondary objective is to establish the procedures that will allow for proper tip dressing/stepper schedules to be developed. The final benefits of this effort and subsequent evaluations will be realized through in-plant verification.

The aim of this document is to describe and detail all of the information and procedures necessary to allow the work to be conducted and realistically completed at different test locations. The contents of the document are as follows:

- Program Requirements
- Limit Test Evaluation
- Establishing the DOE
- Procedures for Qualification of Welding Equipment
- DOE Welding Procedures
- Data Collection and Reporting.

2.0 Program Requirements

2.1 Welding Equipment

In this program, standard automotive resistance welding weldguns will be utilized to produce all welds. Ideally, each test location will utilize a different geometry weldgun. The appropriate capacity transformers are to be available to weld the steel within the constraints of the experimental design. The primary constraints include welding at current levels as high as 20% greater than the expulsion current level, maintaining a phase shift (percent heat) level greater than 60%, and sustaining a welding rate of 25 to 30 welds/minute.

2.2 Instrumentation and Tooling

Each site will have calibrated equipment to measure force and weld current during the day-to-day testing. Edison Welding Institute (EWI) will evaluate the measurement equipment at each site to verify calibration and identify any differences.

EWI will provide each test site with the required fixture for properly locating the parent material to be welded. This fixture will allow each test site to consistently reproduce any combination of factor levels associated with the DOE. Slight modifications to the fixture, which in no manner alter its ability to reproduce the factor levels of the DOE, may be required by each test site. Figure 1 presents the fixture that will be supplied to each test location.

2.3 Other Requirements

Each testing facility will have all the equipment which might be required in order to meet any of the health and safety issues encountered in the program. These will include, but are not limited to:

- Shielding
- Fume removal
- Material handling
- Material storage
- Disposal
- Operator safety

It is the responsibility of each location to meet these requirements.

3.0 Limit Test Evaluation (EWI Only)

Initial A/SP Committee meetings regarding the DOE evaluation of coated steels determined that preliminary work would be required such that accurate estimates could be made regarding the cost and duration of the program. This preliminary work involves conducting two electrode life tests using candidate factors for the DOE. The purpose of these tests is to establish the approximate number of welds that will be required for the longest and shortest electrode life tests associated with the DOE. With this information, candidate test sites will be better able to predict the cost associated with conducting the DOE trials.

3.1 Current Range Evaluation (EWI Only)

One of the major aspects of this program that distinguishes it from previous work examining the weldability of coated steels is the utilization of welding current levels similar to that used in production (i.e., expulsion current levels or higher). In an effort to establish appropriate levels of weld current, six standard current ranges will be established. The minimum current level will be defined as that current which produces expulsion on both welds of a peel coupon. The maximum current level will be defined as that current at which sever electrode sticking occurs (i.e., the electrodes remain attached to the parent sheet) or excessive expulsion is observed. The primary purpose of these current ranges is to identify the maximum current level. By establishing this level, it will be possible to set an appropriate upper current level for the limit tests, which does not immediately result in electrode sticking.

The current range tests will be performed using a scissors weldgun welding on nominally 0.8-mm (0.032-in.) hot-dipped galvanized (HDG) steel. It is not deemed necessary to replicate these current ranges on galvaneal (GA) material as the sticking condition for HDG steel is considered to be more severe. Three tests will be performed for each electrode material of interest (DSC and CuCr). The weld schedule parameters for each current range will include 2.2-kN (500-lbs) weld force and 12 cycles of weld time.

3.2 Limit Test Procedure (EWI Only)

1. Examine the appropriate welding conditions for either the positive or negative factor level limit test (Table 1). For those welding factors which may be altered at any time (i.e., post initial set-up), set the factor level to the nominal level (Table 1). For those welding factors that may not be altered after initial set-up, set the factor level according to the appropriate Limit Test.
    - Note: The purpose of setting the factor levels to the nominal levels shown in Table 1 is to, as much as possible, establish the appropriate weld test current level without having a significant influence from variation of the factor levels.
2. Perform machine setup and electrode alignment using standard manufacturing techniques.

3. Set the current level to a low enough level at which no fusion of material is observed (8.0 kA). Gradually increment the phase shift (percent heat) upward 1-2% (200 A) per peel sample until a weld button of any size or shape is produced (coupon dimensions nominally per the A/SP Weld Quality Test Method Manual).

4. Continue the increase in phase shift/current level until expulsion is observed on the first weld of a peel sample. (Note, the total number of welds required to achieve the expulsion current level should not exceed 30 welds.)

5. Make the appropriate changes to the factor levels as defined for either the positive or negative factor level limit test (i.e., for those factors which were set at their nominal levels, change the level to reflect the appropriate Limit Test). The purpose of the change here will be performed so as to reduce the influence of the various factors on the established current level (Step 4). For the positive factor level limit test, the current level is defined as the expulsion current found in Step 4 plus 2% [this 2% is not 2% phase shift (i.e., percent heat), but rather 2% of the measured current established in Step 4]. For the negative factor level limit test, the current level is defined as the expulsion current (Iexp) found in Step 4 plus 20% (Iexp $\times$ 1.20).

6. Weld five peel test coupons (coupon dimensions nominally per the A/SP Weld Quality Test Method Manual). Measure the maximum and minimum weld button diameters of the second weld from each peel test coupon. Calculate the average button diameter and aspect ratio.

7. Make 90 welds on electrode life weld panels and repeat Step 6.

8. Continue to repeat Steps 6 and 7 until all five welds of two consecutive 100 weld increments have an average button diameter less than $4 \times t^{0.5}$ [t = parent sheet thickness (mm)].

9. Stop the test. The electrode life is the total number of welds reached after the second test set of five welds. (Note, during the analysis of data, neither of the last two sets of weld data will be incorporated. However, recording of these welds is important to guarantee that each individual electrode life test is carried to completion.)

4.0 Design of Experiment

4.1 Selecting the Factors of Interest

One of the first tasks in conducting a DOE evaluation is to select the factors that will be examined. To accomplish this task, a brainstorming session was conducted in which a summary list of candidate factors was determined. To narrow this list to an acceptable level, a factor selection criteria matrix was utilized. The criteria of interest included:

1. **Scope -** Scope refers to the applicability of the factor. Is it relevant to many different welding situations, pieces of equipment etc., or is it restricted to relatively few situations?
2. **Economy of Control -** Can control of the factor be effective with relatively low cost?
3. **Practicality of Control -** Disregarding cost, would control of the factor actually happen, or would it be too cumbersome to put into effect?
4. **Significance as a Single Factor Acting Alone -** What is the estimated influence of the factor on its own?
5. **Significance of the Factor as a Part of Any Multiple-Factor Interactions -** How influential might the factor be in combination with other factors?
6. **Originality of Work -** Does inclusion of this factor advance knowledge or simply repeat work already performed?
7. **Specific Company Needs -** Is inclusion of the factor essential to make the results meaningful to a specific company.
8. **Effect on Weld Button Mean -** Is the factor likely to affect the average button diameter?
9. **Effect on Weld Button Spread -** Is the factor likely to affect the variation in average weld button diameter?
10. **Effect on Aspect Ratio -** Is the factor likely to affect the weld button roundness?

Members of the A/SP DOE of Coated Steels Subcommittee (T. Natale - A.K Steel, N. Clay – Ford Motor Company, L. Lehman – EWI) ranked each of the candidate factors from one to five for each of the above criteria. A cumulative total of these rankings allowed a quantitative ranking of the significance of all candidate factors (Appendix A). Based upon this quantitative ranking and further discussions by the A/SP DOE of Coated Steels Subcommittee, the final factors of interest for the DOE were determined. These factors are presented in Table 2. Comparison of the factors listed in Table 2 and the quantitative list presented in Appendix A shows that the factors to be examined in the DOE do not directly correspond to the "most significant" factors as determined by the factor selection matrix. Table 3 lists the top 25 factors from the selection criteria matrix and when applicable, discusses their respective elimination from the DOE.

4.2 Terms and Definitions of Factors Selected for the DOE

The following presents each of the factors to be investigated in the DOE and a brief description of each factor. Specific factor levels are presented in Table 2.

4.2.1 Weld Current [*Current (I)*]

Trials will be conducted at multiple-current levels at and above the expulsion current level as determined from each trial's initial weld current range.

Notes:

- The expulsion current level is defined as the current level identified through conduction of the Current Adjustment Procedure for Establishing the Expulsion Current Level (Section 6.2).
- The percentage increase of the current is not percent phase shift, percent heat, or percent current setting, but rather a percentage of the measured expulsion current amperage.

4.2.2 Axial Electrode Alignment [*Axial Alignment (A×A)*]

Axial electrode alignment refers to the degree of overlap of the two electrode faces. Ideally, each electrode's vertical neutral axis will be in the same line. For this factor, the level assignments are ideally aligned or having the vertical neutral axis of the electrodes offset by some percentage of the nominal electrode face diameter. Misalignment will occur away from the welder secondary. Determination of the amount of misalignment will be accomplished through the use of micrometer measurements taken at the electrode faces while in the closed position. Figure 2 presents the normally aligned axial alignment condition and an example of an electrode pair that has been offset (25%).

Note:

- Some of the DOE welding trials require adjustment to both the axial alignment (AxA) and edge position (EP) factors. For these trials, the establishment of the edge position should be based upon the electrodes' position prior to adjusting for the AxA factor. In making the correct adjustment for the AxA factor, the adjustment is to be made such that the electrode being offset moves towards the centerline of the parent sheets.

4.2.3 Angular Parent Sheet to Electrode Alignment [*Angular Alignment (AnA)*]

Angular alignment refers to the variation in orientation of the parent sheet to the electrodes. For this factor the levels will include 0-degree offset (ideally aligned), or "X" degrees of offset (here "X" is equal to some number). Figure 3 presents the 0-degree offset condition and an example of a misaligned condition (10 degrees). The tooling that EWI will supply each test site will be capable of orienting the parent materials for the desired levels of angular alignment.

4.2.4 Material Coating Type [*Coating Type (CTyp)*]

Coating type refers to the type of metallic coating layer on the substrate (IF steel). For this factor, the level assignments are either HDG or GA.

4.2.5 Cooling Tube Position (*CTP*)

The cooling tube position factor will allow for an examination of the influence of having a properly located cooling tube. Ideally, the cooling tube will be cut with a 45-degree angle and the tip of the tube will nominally touch the inside surface of the electrode. Refer to Section 6.11 of the Auto/Steel Partnership Weld Quality Test Method Manual for proper tube size and location. For this factor, the levels of interest are "ideally located" and "removed" (i.e., located such that the end of the cooling tube is a minimum of 12.7 mm (0.5 in.) away from the inside surface of the electrode).

4.2.6 Electrode Geometry (*EGm*)

In an effort to match the most commonly used electrodes in industry, three different electrode geometries will be investigated [electrode geometries nominally per the Auto/Steel Partnership Weld Quality Test Method Manual. The electrode geometries of interest include pointed, ball, and truncated electrodes (Figure 4). Each of these electrodes will have a No. 5 cap taper and a 15.9-mm (0.625-in.) diameter body [6.4-mm (0.25-in.) diameter electrode face for the pointed and truncated electrodes]. All of the electrodes will be purchased by EWI and provided to the individual test sites.

4.2.7 Part Fit-Up (*PF*)

Often in industry welding-related problems are the result of upstream process variables. One upstream process variable of interest is part (component) fit-up. To examine the influence of poor component fit-up on weld size/shape variance, three levels of component fit-up will be examined. The levels of component fit-up will be identified as 0, 1, and 2. Each of these numeric values is a multiplier times the parent sheet thickness. The “0” fit-up condition exists when the parent sheets to be welded are in contact with each other [$0 \times t$ (t = parent sheet thickness)]. Similarly, the “1” and “2” fit-up conditions exist when there is a gap between the parent sheets. The distance of this gap being equal to t or $2 \times t$ (t = parent sheet thickness). Figures 5A, -B, and -C respectively depict the “0” fit-up condition, an example of improper component fit-up (levels “1” or “2”), and how the fit-up factor will be simulated in this investigation. Again here, the tooling built for the electrode life trials will be capable of producing all required levels of component fit-up.

4.2.8 Coating Weight (*CW*)

In the automotive industry, typically the primary driver behind the utilization of materials with increased coating weight is improved corrosion resistance. In this program four different coating/coating weight combinations of steels will be evaluated (2-GA, 2-HDG). Appendix C contains information on the parent materials, coating compositions, and coating weights.

4.2.9 Edge Position (*EP*)

Edge position refers to the location of the electrodes' center with respect to the outside edge of the parent sheets. The occurrence of edge welds is becoming more common in industry as decreases in flange width are utilized to reduce vehicle weight. For this study, the edge position factor will incorporate four different edge position locations. These locations will be established by measuring the distance from the edge of the parent sheets to the neutral axis of the electrodes. The four distances are 0.25, 0.5, 1, and 2 times the electrode face diameter. Figure 6 presents a representation of edge position whereby the edge weld is shown with the neutral axis of the electrode located a distance of one half the electrode face diameter away form the parent sheet edge (i.e., $0.5 \times$ electrode face diameter).

Note: For those trials that incorporate adjustment of the axial alignment factor, the edge position is determined by measuring the distance from the edge of the parent sheets to the neutral axis of the electrode closest to the parent sheet edge.

4.2.10 Electrode Material (*EM*)

In this investigation the two electrode materials of interest include Class II CuCr and dispersion strengthen Cu (DSC).

4.2.11 Welding Force (*F*)

In this program, the parent sheet thickness being investigated is nominally 0.8 mm (0.032 in.). This thin gauge of material was chosen, as it is well known that thinner gauges of parent sheet present the worst-case condition for electrode life evaluations. Per the Auto/Steel Partnership Weld Quality Test Method Manual, the recommended level of force for this gauge of material is 2.2 kN (500 lbs). For this investigation the levels of weld force to be examined include 1.9, 2.2, and 2.6 kN (425, 500, and 575 lbs).

4.2.12 Electrode Face Thickness (*EFT*)

The standard electrode face thickness (i.e., the distance from the bottom of the water hole to the electrode face) for the electrodes to be examined in this investigation is nominally 10.0 to 12.7 mm (0.4 to 0.5 in.). For this factor, the levels to be examined include the standard electrode face thickness for each cap type (12 cap types exist in this program – 2 materials × 2 genders × 3 geometries), and various reductions from the standard thickness. For each cap type, the electrode face thickness will be measured from five electrodes. The average of these measured values will be considered the baseline for that cap type. The reduced face thickness will be achieved by machining the inside surface of the electrode face. The amount of reduction will be 0, 1, 2, or 3 mm (0.000, 0.040, 0.080, or 0.120 in.) off of the baseline value. EWI will perform all of the work required to achieve the various levels of electrode face thickness.

4.2.13 Force Build-Up *(FB)*

The percentage of force build-up during the welding process is dependent upon the cylinder size, line pressure, port size, squeeze time, etc. Squeeze time is the time allowed to realize the desired welding force prior to passing current. With increased demands on production rates, it is not uncommon to have reductions in the allotted squeeze time. Should the squeeze time be reduced too much, the welding current will begin to flow while the machine is still establishing the desired force level. To better understand the impact of having the welding current begin to pass during a rising force cycle, this investigation will evaluate welds made with a squeeze time of <70, nominally 85, or >99% force build-up. EWI will visit each test location and establish the required squeeze times to allow for the variations in force build-up for each of the weld force levels examined in the DOE.

Note:

- In determining the required squeeze times for each level of force build-up, in conjunction with each level of weld force, it may be determined that there is an insignificant difference in time (squeeze time) required to achieve two of the three levels. In such cases, modifications will be made such that the three levels of force build-up are more clearly defined.

4.2.14 Electrode Gender (*EGe*)

Typically, across the Big 3 there are preferences with regard to electrode gender. The electrode gender factor was included in the DOE to allow companies to evaluate the performance of their standard electrode gender. The two levels for the electrode gender factor are male versus female electrode caps.

4.2.15 Site *(S)*

To allow for timely completion of this effort and to incorporate the noise associated with different facilities, multiple tests sites will be utilized for conducting the trials of the DOE. Analysis of the combined data from each test location will allow for an overall understanding of the influence of each DOE factor, regardless of test location. Comparison of the data from each test location will allow for a general understanding of any differences that may be observed. However, due to the numerous influences which exists such as machine type, machine rigidity, power, operator, etc., any differences which are observed will not be attributable to one specific influence.

4.3 Establishing the DOE Matrix

Based upon recommendations by N. A. Technologies, the experimental design to be used for the screening DOE is an N-optimal design. Use of this design will allow the results to be used in the “training” of a neural net. The experimental matrix is provided in Appendix B. (Note, DOE data sheets will be supplied by EWI to each test location for clear definition of the factors levels associated with each DOE trial.)

5.0 Procedures for Calibration of Equipment

The procedure for the calibration/definition of equipment will be based on the draft ISO 669 document. This procedure largely defines mechanical performance requirements of the welding systems. Since EWI will be conducting these calibrations at each of the participating facilities, detailed information is not included in this document. Some of the efforts may include, but are not limited to:

1. Listing machine specifications, manufacturer, age, cylinder size, available line pressure, etc.
2. Measuring force build-up rates using strain gauges.
3. Measuring deflections under load.
4. Evaluating the water supply system.
5. Measuring the system's follow-up capability

6.0 DOE Welding Procedures

One of the main emphases of this program is to simulate production conditions as closely as possible. As such, no additional efforts such as electrode conditioning will be performed. In order to establish tip life without the effect of electrode tip dressing or weld schedule stepping, neither of these actions will be taken during the tests associated with this program.

6.1 Initial Machine Set-up

To properly set the factors levels, examine the appropriate welding conditions for DOE trial to be conducted. Table 2 presents the DOE test factors and factor levels. For those welding factors that may be altered after establishing the specific trial current level, set the factor level to the nominal level. For those equipment-related welding factors that may not be altered after initial set-up, set the factor level according to the appropriate DOE trial.

- Note: The purpose of initially setting the machine factor levels to the nominal condition is to, as much as possible, prevent the variation in factor levels from influencing the established trial current level.

6.2 Current Adjustment Procedure for Establishing the Expulsion Current Level

The following procedure is a modification of the Chrysler Laboratory Procedure LP-461K-173. To allow for an improved understanding of this procedure, Figure 7 displays a flow chart that represents the steps required to establish the expulsion current level.

Step 1: Set the current level to a low enough level at which no expulsion of material is observed when making a weld (8.0 kA). Gradually increment the current upward [1-3% (200-400 A) per weld] until expulsion is observed (Note: the weld spacing should be maintained at 15 to 20 mm at all times).

Step 2: Record the "First Expulsion Current Level" (FIexp) on the respective DOE Data Collection Sheet (example sheets shown in Appendix D).

Step 3: Reduce the phase shift (percent heat) 5% from the level at which the FIexp was established and make four welds on a new set of parent material strips.

Step 4: Increase the phase shift 3% and make four welds (maintain the 15- to 20-mm weld spacing). If two or more of the four welds show expulsion, go to Step 5. If one or less welds shows expulsion, go to Step 6.

Step 5: Reduce the phase shift by 2% and make four welds. If two or more of the four welds show expulsion, repeat Step 5. If one or less welds shows expulsion, go to Step 6.

Step 6: Increase the phase shift by 1% and make four welds. If two or more of the four welds show expulsion, go to Step 7. If one or less of the welds show expulsion, repeat Step 6.

Step 7: Record the current level established in Step 6 on the DOE Data Collection Sheet as the "Expulsion Current Level" (Iexp).

Step 8: Look up the specific DOE Trial current level (1.02, 1.08, 1.14, or 1.2 $\times$ Iexp) from the DOE matrix (Appendix B).

Step 9: Calculate the "Actual Test Current Level" for the specific DOE trial.

Example: If the DOE trial of interest calls for a current level 20% higher than the expulsion current level (Iexp), multiply Iexp by 1.2. This calculated current level is the "Actual Test Current Level".

Step 10: In an iterative manner, adjust the percent phase shift (percent heat) upward and make welds until a current level is obtained that is as close to the "Actual Test Current Level" as can be achieved (always maintain the 15- to 20-mm weld spacing). Record the Doe Trial current level on the DOE Data Collection Sheet.

Note 1: The total number of welds required to establish the "Actual" DOE trial current level should be less than 40. If more than 40 welds are required, change the electrode tips and begin again.

Note 2: A maximum of 24 welds are to be placed on a pair of parent material strips. If during the above procedure it is necessary to utilize a new pair of parent material strips, reduce the phase shift 5% below whatever phase shift is being utilized and make four shunt welds on the new parent material strips. Once the shunt welds have been made, adjust the phase shift back to the appropriate level and continue the procedure.

Note 3: Do not split the sets of four welds between two different pairs of parent material strips.

Note 4: Properly label all of the strips utilized to establish each trials current level. Specifically label the welds associated with the:

- First Expulsion Current Level (FIexp)
- Expulsion Current Level (Iexp)
- Actual Test Current Level

6.3 Setting Up the Machine for the Specific DOE Trial

Make the appropriate changes to the factor levels as defined for the specific DOE trial (i.e., for those factors which were set at their nominal levels, change the level to reflect the appropriate DOE trial).

6.4 Conducting a DOE Electrode Life Test

1. Make ten welds along a strip of the appropriate parent material for the DOE trial [15- to 20-mm (0.6- to 0.78-in.) weld spacing]. Record the measured weld current of the sixth through tenth weld on the corresponding DOE data sheet. Upon destructive peel, measure the maximum and minimum button diameter of the sixth through tenth weld. Record these values, along with the failure morphology (as defined in the Auto/Steel Partnership Weld Quality Test Method Manual) on the DOE data sheets. EWI will calculate the average button diameter and aspect ratio.
2. Make 90 welds on electrode life weld strips (25 welds/strip) and repeat Step 1.
   - Note: To allow for the various factors of interest, the electrode life tests in this program will be conducted on 31.25-mm (1.25-in.) wide strips of steel. The weld spacing will be 15-20 mm (0.6-0.78 in.) and the weld rate will be nominally 25 welds/minute.
3. Continue to repeat Steps 1 and 2 until all five of the measured welds from two consecutive 100-weld increments have an average button diameter less than the minimum acceptable average button diameter.
   - Note: The minimum acceptable average button diameter = $4 \times t^{0.5}$ [t = parent sheet thickness (mm)]. For the material being using in this program, the minimum acceptable average button diameter = $4 \times (0.8)^{0.5}$ = 3.6 mm.
4. Make sure all relevant data has been listed on the DOE Data Collection Sheets and return to a copy to EWI.

7.0 Data Collection and Reporting

Appendix D presents an example DOE trial data collection sheet package. EWI will supply each test location with multiple DOE trail data sheet packages. It is recommended that each site make a master copy.

Upon beginning a DOE trial, the operator should fill in the specific DOE trial number, date, and her/his name. Spaces are provided for the operator to enter the initial factor level settings used to determine FIexp and Iexp. Once each of these expulsion current levels has been obtained, their values should be recorded on the data sheet in the proper location. Again, the “desired” current level will be that which corresponds to the given DOE trial, while the “actual” testing current level corresponds to that which could be achieved. It should be noted that the actual current level will often not exactly match the desired current level; however, they should be similar.

Each data sheet contains regions for the measured weld current, the maximum button diameter, and the minimum button diameter to be recorded from the five test welds of each 100-weld interval of the electrode life test. Spaces are also provided for calculations of the average button diameter and aspect ratio, along with the failure morphology and any occurrence of expulsion (identification of expulsion will be denoted by placing an “E” along with the measured current in the measured current column). EWI will conduct the calculations of the average button diameter and the aspect ratio. Each test site is responsible for filling in all other information. Copies of the completed DOE trial data sheets will be returned on a weekly basis to EWI.

8.0 Moving Forward

Upon completion of the 126 electrode life tests the results will be forwarded to N.A. Technologies for development of the neural network model. As part of this effort, N.A. Technologies will make a recommendation for additional experimental trials that will help to increase the confidence in the model's output. Conduction of these additional experimental trials may be required by any of the three test sites. The procedures followed for conduction of these additional electrode life tests will identically follow the procedures outlined in this document for the original 126 trials.

Table 1. Limit Test Factors and Factor Levels

Factor	Limit Test Factor Levels		Nominal Factor Level
Weld current	-1 +1	1.20 × Iexp 1.02 × Iexp	Not applicable
Flow rate	-1 +1	0.07 cfm (0.5 gal/min) 0.20 cfm (1.5 gal/min)	0.13 cfm (1.0 gal/min)
Hold time	-1 +1	2 cycles 10 cycles	10 cycles
Coating type	-1 +1	HDG GA	Not applicable
Cooling tube position	-1 +1	>12.5 mm (0.5 in.) removed Nominally touching	Not applicable
Electrode geometry	-1 +1	A-nose E-nose	Not applicable
Part fit-up	-1 +1	Poor fit-up Ideal fit-up	Ideal fit-up
Impact velocity	-1 +1	1 m/s (4 in./sec) 0.5 m/s (2 in./sec)	0.5 m/s (2 in./sec)
Electrode material (EM)	-1 +1	CuCr CuCr	CuCr
Welding force (F)	-1 +1	1.9 kN (425 lbs) 2.6 kN (575 lbs)	2.2 kN (500 lbs)
Electrode face thick (EFT)	-1 +1	Normal Normal	Normal
Force build-up (FB)	-1 +1	<70% Build-up >90% Build-up	>90% Build-up

Table 2. DOE Test Factors and Factor Levels

Factor	DOE Trial Factor Levels		Nominal Factor Level
Weld current (I)	-2 -1 +1 +2	1.02 × Iexp 1.08 × Iexp 1.14 × Iexp 1.20 × Iexp	Not Applicable
Axial alignment (AxA)	-1 0 +1	30% offset 15% offset 0% offset	0% offset
Angular alignment (AnA)	-1 0 +1	20-degrees offset 10-degrees offset 0-degrees offset	0-degrees offset
Coating type (CTyp)	-1 +1	HDG GA	Not Applicable
Cooling tube position (CTP)	-1 +1	12.5 mm (0.5 in.) removed Nominally touching	Not Applicable
Electrode geometry (EGm)	-1 0 +1	Ball (Dome) Pointed Truncated	Not Applicable
Part fit-up (PF)	-1 0 +1	2 × t gap 1 × t gap 0 × t gap	0 × t Gap
Coating weight (CW)	-1 +1	A & B (GA) C & D (HDG)x	Not Applicable
Edge position (EP)	-2 -1 +1 +2	ENA 0.25 × Ediam from edge ENA 0.50 × Ediam from edge ENA 1.00 × Ediam from edge ENA 2.00 × Ediam from edge	ENA 2.00 × Ediam from edge (ENA = "Electrode Neutral Axis")
Electrode material (EM)	-1 +1	DSC CuCr	Not Applicable
Welding force (F)	-1 0 +1	1.9 kN (425 lbs) 2.2 kN (500 lbs) 2.6 kN (575 lbs)	2.2 kN (500 lbs)
Electrode face thick. (EFT)	-2 -1 +1 +2	3 mm removed 2 mm removed 1 mm removed 0 mm removed	Not Applicable
Force build-up (FB)	-1 0 +1	70% Build-up 85% Build-up 99% Build-up	99% Build-up
Electrode gender (EGe)	-1 +1	Female Male	Not Applicable
Test location	-1 0 +1	A B C	Not Applicable

Table 3. Top Candidate Factors From the Selection Criteria Matrix and Their Use in the DOE

Candidate Factor No.	DOE Factor No.	Factor	Consideration Reasoning
1	1	Current	Selected as DOE factor.
2	2	Axial elec. align.	Selected as DOE factor.
3		Tip dresser sch.	The tip dresser and stepper schedules are considered significant. However, as testing would require multiple electrode life tests, inclusion was not appropriate for a screening type DOE.
4		Stepper sch.	Same as Candidate Factor 3.
5	3	Angular elec. align.	Selected as DOE factor.
6		Equip. Condition	The "equip. cond." factor was considered too broad. The difference in results never really identifiable with a particular attribute of the equipment.
7		Gages and stack-up	The thinnest gauge of material presents the worst case condition. Specific stack-ups beyond a similar gage two layer stack-up are too specific for a screening DOE.
8		Exp. effect on elec.	Considered to be similar to the weld current factor.
9	4	Coating type	Selected as DOE factor.
10		Weld time	Large variations in weld time are typically associated with variations in gage and stack-up. For the two-layer stack-up used in the screening DOE, standard practice will dictate the weld time utilized.
11	5	Cooling tube pos.	Selected as DOE factor.
12		Init. elec. face. diam.	Similar reasoning as presented for Cand. Factor 10.
13	6	Electrode geom.	Selected as DOE factor.
14	7	Part fit-up	Selected as DOE factor.
15		Nom. elec. face. diam.	Similar reasoning as presented for Cand. Factor 10.
16	8	Coating thickness	Selected as DOE factor.
17	9	Edge position	Selected as DOE factor.
18		Machine rigidity	In terms of gun arm rigidity this factor is considered significant. However, examination of this factor is believed to be more suited for post-screening test evaluations.
19	10	Force build-up	Selected as DOE factor.
20	11	Electrode material	Selected as DOE factor.
21	12	Welding force	Selected as DOE factor.
22		Variations in coating	Considered too costly to include in the DOE.
23	13	Elect. face thick.	Selected as DOE factor.
24		Flange width	Considered to be dominated by the edge position factor.
25		Bulk resistivity	Considered to be associated with gauge and stack-up.
41	14	Elec. gender	Selected as DOE factor.

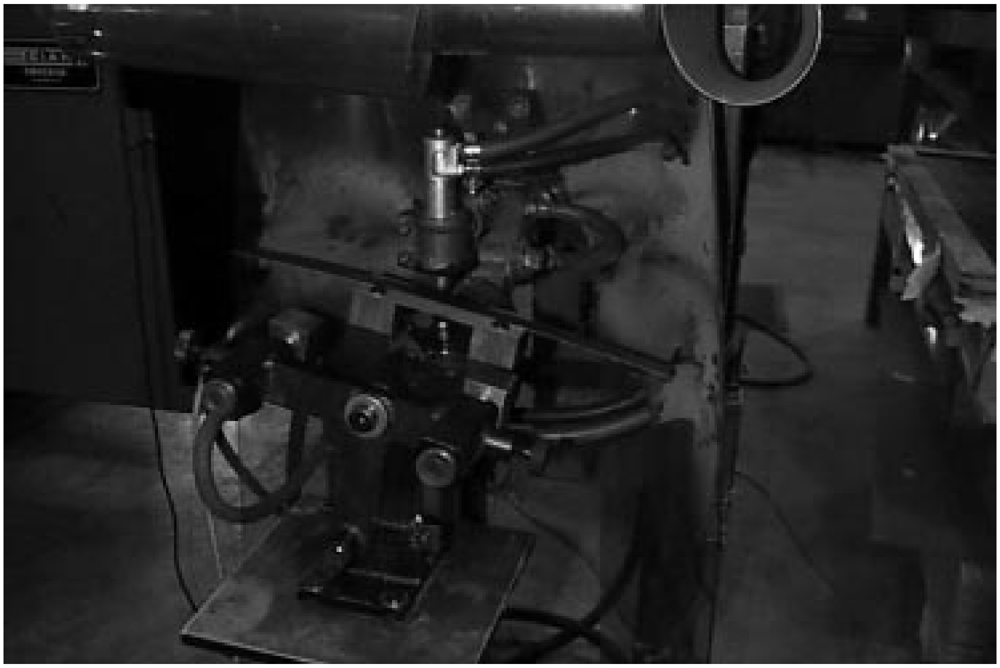

Figure 1. **DOE Testing Fixture and Weldgun**

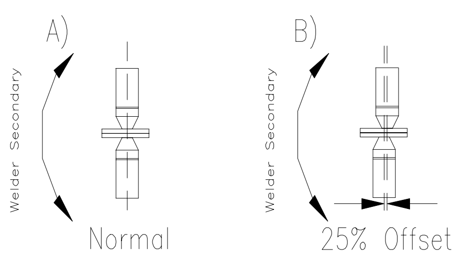

Figure 2. **Axial Alignment** [(A) Normal, (B) 25% Offset]

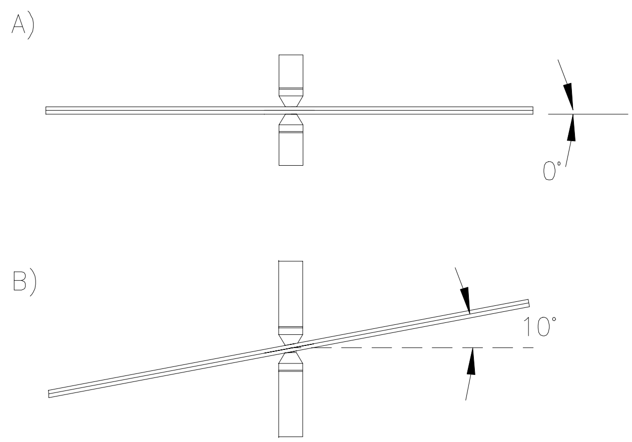

Figure 3. **Angular Alignment** [(A) Normal, (B) 10-Degree Offset]

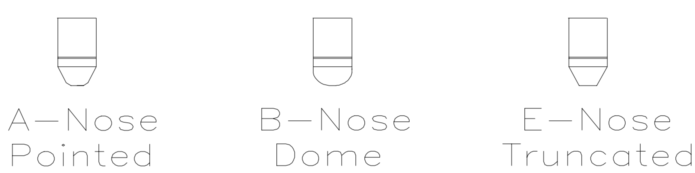

Figure 4. **Pointed, Dome, and Truncated Electrodes**

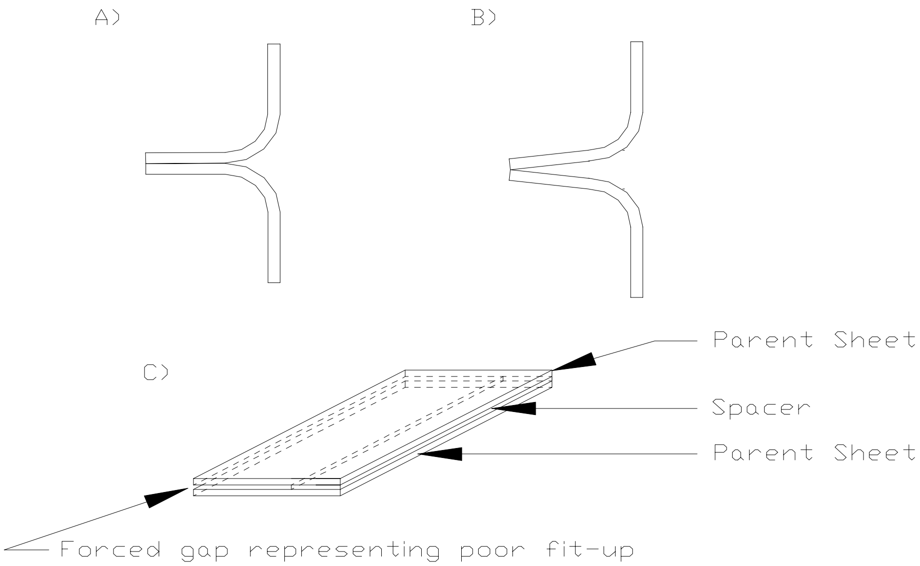

Figure 5. (A) Proper Fit-up, (B) Improper Fit-up, and (C) Simulated Improper Fit-up

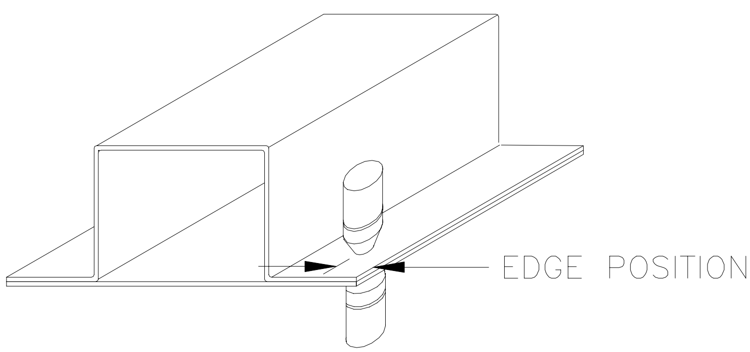

Figure 6. Edge Position

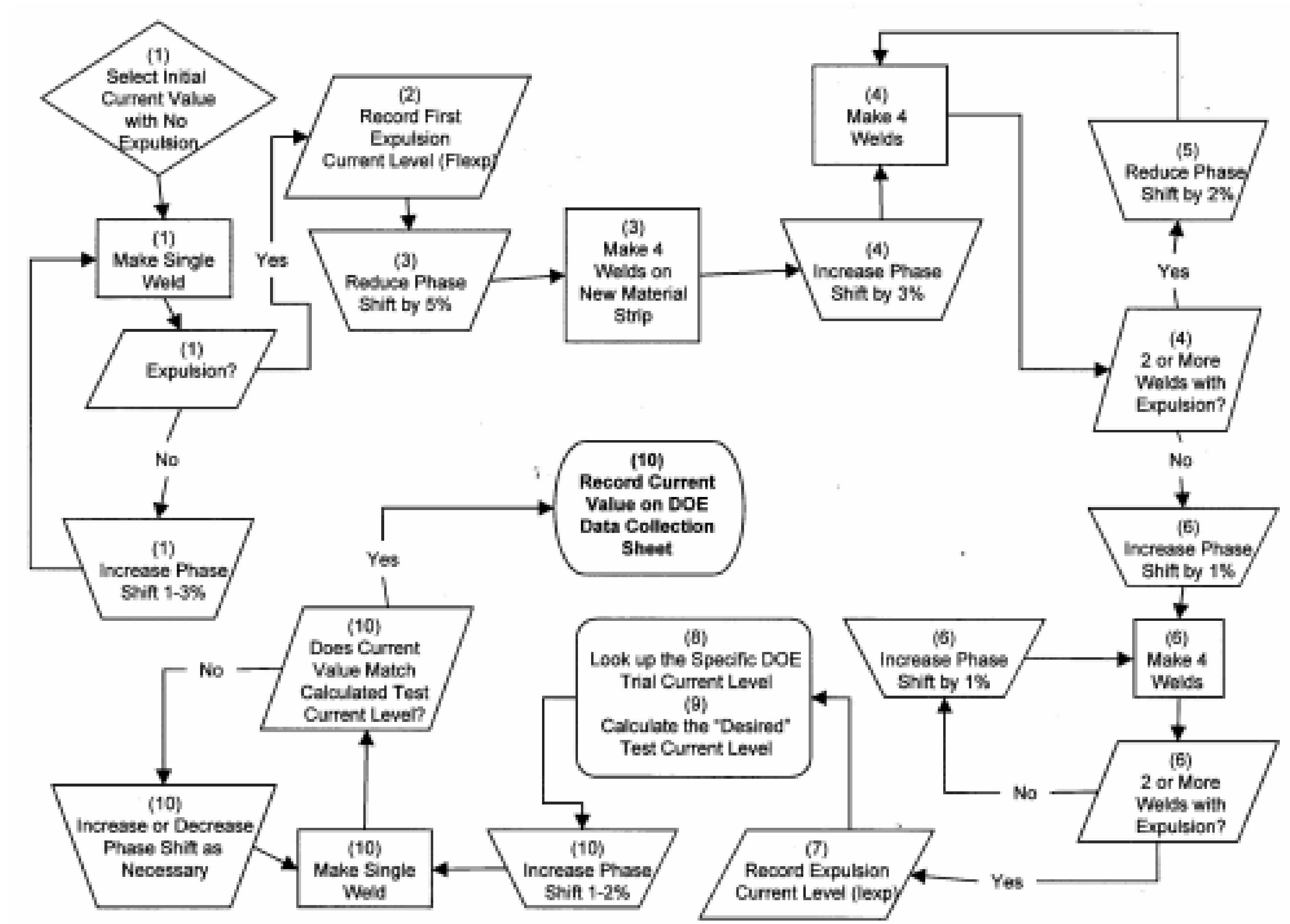

Figure 7. Establishment of the DOE Trial Current Level Flowchart

Appendix A

A Quantitative Ranking of the Candidate DOE Factors

Appendix B

DOE Test Matrix

Trial #	I	AxA	AnA	CTyp	CTP	EGm	PF	CW	EP	EM	F	EFT	FB	EGe	Location
1	1.2	0	10	HDG	0	Dome	1	60/60	2	DSC	2.6	1	99	M	A
2	1.2	0	20	GA	12.5	Point	2	45/45	2	DSC	1.9	0	99	M	A
3	1.02	30	10	HDG	12.5	Dome	0	60/60	2	DSC	1.9	3	99	M	A
4	1.02	30	0	GA	12.5	Dome	2	60/60	2	CuCr	2.6	0	70	F	A
5	1.02	30	20	GA	12.5	Truncate	0	60/60	2	DSC	2.6	3	99	F	C
6	1.2	15	0	HDG	12.5	Dome	0	60/60	2	DSC	2.6	3	70	M	A
7	1.14	0	20	HDG	12.5	Dome	0	60/60	2	CuCr	2.6	3	70	F	A
8	1.2	0	20	GA	12.5	Truncate	0	45/45	2	DSC	2.6	3	70	M	C
9	1.2	0	0	HDG	0	Point	0	60/60	2	CuCr	1.9	0	99	M	C
10	1.2	30	20	HDG	12.5	Dome	2	60/60	0.25	DSC	1.9	3	99	F	C
11	1.02	0	20	GA	0	Dome	2	60/60	2	CuCr	1.9	3	99	M	C
12	1.2	30	0	GA	0	Dome	0	60/60	0.25	CuCr	2.6	0	99	M	A
13	1.02	0	20	HDG	12.5	Dome	0	60/60	2	CuCr	2.6	0	99	M	A
14	1.2	30	20	GA	12.5	Dome	0	60/60	2	CuCr	1.9	3	70	F	C
15	1.2	0	0	HDG	12.5	Truncate	1	60/60	2	CuCr	1.9	0	99	F	C
16	1.2	0	0	HDG	12.5	Point	0	60/60	2	CuCr	2.6	3	70	F	C
17	1.2	15	0	HDG	0	Truncate	0	98/98	2	DSC	1.9	0	85	M	C
18	1.02	0	0	GA	0	Truncate	0	60/60	2	DSC	2.2	0	99	M	C
19	1.2	30	0	GA	12.5	Truncate	2	60/60	2	DSC	2.6	3	70	M	A
20	1.02	0	0	HDG	0	Truncate	0	98/98	2	CuCr	2.2	3	70	M	C
21	1.02	0	10	HDG	12.5	Dome	2	98/98	2	DSC	2.6	3	99	F	C
22	1.2	30	20	HDG	0	Dome	0	60/60	2	DSC	1.9	0	99	M	A
23	1.2	0	20	GA	0	Point	2	60/60	2	CuCr	1.9	3	70	F	C
24	1.08	30	0	HDG	0	Truncate	2	60/60	2	DSC	2.6	0	70	M	C
25	1.2	0	0	GA	0	Truncate	1	60/60	2	CuCr	1.9	0	99	F	C
26	1.02	0	20	HDG	12.5	Truncate	2	60/60	2	CuCr	1.9	0	70	M	B
27	1.2	30	10	HDG	0	Dome	2	98/98	2	DSC	1.9	0	99	M	C
28	1.02	15	0	GA	12.5	Dome	1	45/45	2	DSC	1.9	0	99	M	C
29	1.02	30	20	HDG	0	Truncate	2	60/60	0.25	CuCr	2.2	3	70	F	A
30	1.14	0	20	GA	12.5	Truncate	0	60/60	2	DSC	1.9	0	99	F	A
31	1.14	0	0	GA	12.5	Truncate	2	60/60	2	CuCr	1.9	3	85	M	C
32	1.02	30	20	HDG	0	Dome	0	98/98	0.5	CuCr	2.6	3	99	F	A
33	1.02	30	20	HDG	12.5	Point	0	98/98	2	CuCr	1.9	0	99	M	C
34	1.02	30	20	GA	0	Dome	2	45/45	0.5	DSC	2.6	0	99	F	C
35	1.02	0	20	GA	12.5	Dome	0	45/45	0.25	DSC	2.2	3	70	F	A
36	1.2	0	20	GA	12.5	Point	0	45/45	2	DSC	2.2	0	70	F	C
37	1.2	0	0	HDG	0	Dome	2	60/60	0.25	CuCr	1.9	0	70	F	C
38	1.2	0	20	GA	12.5	Truncate	2	45/45	0.25	CuCr	2.6	0	99	M	A
39	1.2	0	20	HDG	12.5	Truncate	2	98/98	2	DSC	1.9	0	70	F	A
40	1.14	0	20	HDG	0	Dome	0	60/60	2	DSC	2.6	3	70	M	C

Trial #	I	AxA	AnA	CTyp	CTP	EGm	PF	CW	EP	EM	F	EFT	FB	EGe	Location
41	1.02	30	20	HDG	0	Truncate	2	60/60	0.25	DSC	1.9	3	99	M	A
42	1.2	0	0	GA	12.5	Dome	0	45/45	1	DSC	2.6	0	99	M	A
43	1.14	30	20	GA	0	Dome	0	45/45	2	DSC	2.6	3	99	F	C
44	1.2	30	10	HDG	12.5	Dome	2	98/98	2	CuCr	1.9	0	99	F	A
45	1.08	0	0	GA	12.5	Truncate	2	60/60	2	DSC	1.9	0	70	F	C
46	1.08	0	20	GA	12.5	Dome	2	45/45	2	CuCr	2.6	2	99	F	A
47	1.2	0	20	HDG	12.5	Dome	2	98/98	2	CuCr	2.6	0	85	M	A
48	1.02	30	0	GA	12.5	Dome	1	60/60	2	CuCr	2.6	3	99	M	A
49	1.02	15	0	HDG	0	Truncate	2	60/60	2	DSC	2.2	3	99	M	C
50	1.2	0	0	HDG	0	Point	0	60/60	0.25	CuCr	1.9	3	70	F	A
51	1.2	0	20	GA	0	Truncate	0	45/45	2	CuCr	2.2	0	70	M	C
52	1.2	30	20	HDG	0	Point	1	98/98	2	CuCr	1.9	3	70	F	A
53	1.02	0	20	HDG	12.5	Truncate	0	98/98	2	DSC	1.9	3	85	M	C
54	1.08	30	20	HDG	12.5	Truncate	2	98/98	2	CuCr	2.6	0	70	M	C
55	1.02	15	20	HDG	0	Truncate	0	98/98	2	CuCr	2.6	0	99	F	A
56	1.14	0	0	GA	12.5	Dome	2	45/45	2	CuCr	1.9	2	70	F	A
57	1.02	30	20	HDG	0	Dome	0	60/60	2	CuCr	2.6	3	99	M	C
58	1.02	30	0	GA	0	Truncate	0	45/45	0.25	DSC	2.6	3	70	F	A
59	1.02	0	20	HDG	12.5	Truncate	2	60/60	0.25	DSC	1.9	0	99	F	B
60	1.2	0	0	HDG	0	Dome	2	98/98	2	DSC	2.6	3	99	F	C
61	1.14	30	20	GA	0	Truncate	2	45/45	2	DSC	1.9	3	70	M	A
62	1.14	15	0	GA	0	Truncate	0	45/45	2	DSC	1.9	0	99	F	A
63	1.02	0	20	HDG	0	Dome	0	98/98	2	DSC	1.9	2	99	F	C
64	1.02	15	20	GA	12.5	Truncate	2	60/60	2	CuCr	2.6	0	99	F	C
65	1.02	30	10	GA	0	Dome	0	60/60	0.25	CuCr	2.2	0	99	F	A
66	1.14	0	0	HDG	12.5	Dome	1	98/98	2	DSC	1.9	2	70	M	C
67	1.02	30	20	GA	12.5	Dome	0	60/60	0.5	DSC	2.6	3	99	M	B
68	1.08	30	20	HDG	12.5	Dome	0	98/98	2	DSC	2.6	2	70	F	C
69	1.14	30	20	GA	12.5	Dome	1	60/60	2	CuCr	2.6	3	70	F	A
70	1.2	0	0	GA	0	Dome	0	60/60	0.25	CuCr	1.9	1	99	M	C
71	1.14	30	0	HDG	12.5	Dome	2	60/60	0.25	DSC	2.6	0	70	F	C
72	1.14	0	20	HDG	0	Truncate	0	98/98	2	CuCr	2.6	0	70	F	A
73	1.14	30	0	GA	12.5	Point	2	45/45	2	DSC	1.9	3	70	M	C
74	1.02	30	0	HDG	12.5	Dome	2	98/98	2	CuCr	2.6	0	99	F	B
75	1.02	30	0	HDG	0	Point	2	60/60	2	CuCr	1.9	0	99	M	A
76	1.02	15	20	HDG	12.5	Truncate	0	60/60	2	DSC	2.2	0	99	F	C
77	1.2	30	20	GA	0	Dome	2	45/45	1	CuCr	2.6	0	99	F	C
78	1.02	0	20	GA	0	Dome	2	60/60	0.5	DSC	1.9	3	70	M	A
79	1.14	15	20	GA	12.5	Dome	0	45/45	2	DSC	1.9	3	99	M	C
80	1.02	30	0	HDG	0	Dome	2	60/60	2	CuCr	2.6	1	70	M	C

Trial #	I	AxA	AnA	CTyp	CTP	EGm	PF	CW	EP	EM	F	EFT	FB	EGe	Location
81	1.14	0	20	HDG	0	Truncate	2	60/60	1	CuCr	2.6	0	99	F	A
82	1.2	30	0	GA	12.5	Truncate	2	60/60	2	CuCr	2.6	0	85	F	A
83	1.02	30	20	GA	12.5	Dome	2	45/45	0.5	DSC	1.9	3	99	F	B
84	1.08	30	0	GA	12.5	Dome	0	45/45	2	CuCr	1.9	0	99	F	B
85	1.02	0	0	GA	0	Dome	0	60/60	0.5	DSC	2.6	3	70	F	C
86	1.02	30	20	GA	0	Truncate	2	60/60	2	DSC	1.9	2	70	M	C
87	1.2	30	10	GA	12.5	Dome	2	60/60	0.25	DSC	2.6	0	70	F	A
88	1.2	0	10	HDG	0	Dome	2	60/60	2	CuCr	1.9	3	99	M	C
89	1.2	30	0	HDG	12.5	Point	1	60/60	2	DSC	1.9	3	99	F	B
90	1.2	30	20	HDG	12.5	Dome	2	60/60	0.25	DSC	2.6	3	85	F	A
91	1.02	30	0	HDG	0	Truncate	0	98/98	1	DSC	2.6	0	70	M	A
92	1.02	0	0	HDG	0	Dome	1	60/60	2	DSC	2.6	0	70	M	C
93	1.02	0	0	HDG	0	Dome	1	60/60	2	DSC	1.9	0	99	F	A
94	1.2	0	20	HDG	12.5	Dome	0	98/98	2	DSC	2.2	3	70	F	A
95	1.14	30	20	GA	12.5	Point	2	60/60	2	DSC	2.6	3	70	F	C
96	1.02	15	0	GA	12.5	Dome	1	60/60	0.5	DSC	2.6	0	70	M	C
97	1.02	15	0	GA	0	Truncate	2	45/45	2	DSC	2.6	0	99	M	A
98	1.02	15	0	HDG	12.5	Truncate	2	60/60	2	DSC	2.6	2	70	F	C
99	1.02	0	10	GA	12.5	Truncate	0	45/45	0.5	DSC	2.6	0	70	M	A
100	1.2	0	10	GA	12.5	Truncate	2	60/60	0.25	CuCr	1.9	3	70	F	A
101	1.02	0	20	HDG	0	Point	0	60/60	2	CuCr	2.6	3	99	M	A
102	1.2	30	20	GA	0	Point	2	45/45	2	DSC	2.6	3	85	M	A
103	1.02	0	20	HDG	0	Dome	2	98/98	2	CuCr	1.9	2	99	F	A
104	1.02	30	0	HDG	0	Dome	2	98/98	0.25	DSC	1.9	3	85	F	C
105	1.02	30	10	HDG	12.5	Truncate	0	60/60	2	DSC	1.9	0	70	M	A
106	1.08	0	20	HDG	0	Dome	0	98/98	0.25	DSC	2.2	0	70	M	C
107	1.08	0	0	HDG	0	Truncate	0	98/98	2	DSC	1.9	0	70	F	A
108	1.2	30	0	GA	0	Point	0	45/45	0.25	CuCr	2.6	3	70	F	C
109	1.02	0	0	HDG	12.5	Dome	0	60/60	0.5	DSC	2.6	3	70	F	C
110	1.2	30	20	HDG	12.5	Truncate	2	98/98	0.25	CuCr	2.6	0	70	F	C
111	1.02	30	10	HDG	0	Truncate	0	60/60	2	CuCr	2.6	2	99	F	C
112	1.02	0	0	GA	12.5	Point	2	45/45	0.5	CuCr	1.9	3	99	M	A
113	1.02	30	20	HDG	0	Dome	2	60/60	2	DSC	2.6	1	70	F	B
114	1.02	30	20	HDG	12.5	Point	2	60/60	2	DSC	1.9	3	70	M	A
115	1.14	0	20	HDG	0	Truncate	2	98/98	0.25	CuCr	1.9	0	99	F	C
116	1.02	15	0	GA	12.5	Truncate	0	60/60	0.25	CuCr	2.6	3	70	M	B
117	1.02	0	0	HDG	12.5	Truncate	2	60/60	0.25	DSC	1.9	3	99	F	B
118	1.02	30	0	HDG	0	Point	2	98/98	2	CuCr	2.6	3	99	F	B
119	1.2	0	10	GA	0	Dome	2	45/45	0.25	DSC	1.9	3	99	F	A
120	1.2	15	20	HDG	12.5	Dome	0	98/98	2	DSC	1.9	3	99	M	A
121	1.2	30	10	GA	12.5	Dome	0	60/60	2	DSC	1.9	0	70	F	B
122	1.2	30	0	HDG	12.5	Truncate	0	60/60	1	DSC	1.9	3	99	M	C
123	1.2	0	10	GA	0	Dome	2	60/60	0.5	DSC	2.6	0	99	M	C
124	1.02	0	20	GA	0	Truncate	2	45/45	2	DSC	2.6	1	85	F	A
125	1.2	30	0	HDG	0	Truncate	1	60/60	2	CuCr	2.6	3	85	M	A
126	1.02	0	20	GA	12.5	Truncate	0	60/60	2	CuCr	2.6	1	99	F	A

Appendix C

Parent Material, Coating Composition, and Coating Weight

NSL ANALYTICAL SERVICES, INC.
FORMERLY NATIONAL SPECTROGRAPHIC LABORATORIES
QUALITY MATERIALS & ENVIRONMENTAL TESTING SINCE 1945

7650 HUB PARKWAY, CLEVELAND, OHIO 44125
PHONE: (216) 447-1550 FAX: (216) 447-0716
(800) 497-6752
HTTP://www.nslanalytical.com

Edison Welding Institute
1250 Arthur E. Adams Drive
Columbus, OH 43221

Attn: Delores Suckow

Date: 1/20/99
Report No: 28355
P.O. No: 98-1995
Page 4 of 4

Client Description: **Carbon Steel**

NSL Lab No	Sample ID	Test	Results/Units
990000692	Job #40900CSP A		
		Al	0.032 %
		B	<0.0005 %
		C	<0.01 %
		Cb	0.034 %
		Co	<0.05 %
		Cr	<0.10 %
		Cu	<0.05 %
		Mn	0.11 %
		Mo	<0.05 %
		Ni	<0.10 %
		P	0.011 %
		S	0.010 %
		Si	<0.10 %
		Sn	<0.01 %
		Ta	<0.10 %
		Ti	0.040 %
		V	<0.01 %
		W	<0.10 %
		Zr	<0.01 %

Sample Submitted by Larry Lehman.

Reporting Officers

R04

Steven M. Podolan, Vice President Quality
Lisa R. Potoma, Quality Assurance
David M. Kluk, Laboratory Manager

NADCAP MATERIAL TESTING LABORATORY

NSL ANALYTICAL SERVICES, INC.
FORMERLY NATIONAL SPECTROGRAPHIC LABORATORIES
QUALITY MATERIALS & ENVIRONMENTAL TESTING SINCE 1945

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Edison Welding Institute
1250 Arthur E. Adams Drive
Columbus, OH 43221

Attn: Delores Suckow

Date: 1/20/99
Report No: 28355
P.O. No: 98-1995
Page 3 of 4

Client Description: **Carbon Steel**

NSL Lab No	Sample ID	Test	Results/Units
990000691	Job #40900CSP B		
		Al	0.044 %
		B	<0.0005 %
		C	<0.01 %
		Cb	<0.01 %
		Co	<0.05 %
		Cr	<0.10 %
		Cu	<0.05 %
		Mn	<0.10 %
		Mo	<0.05 %
		Ni	<0.10 %
		P	0.012 %
		S	0.008 %
		Si	<0.10 %
		Sn	<0.01 %
		Ta	<0.10 %
		Ti	0.044 %
		V	<0.01 %
		W	<0.10 %
		Zr	<0.01 %

Reporting Officers

R04

Steven M. Podolan, Vice President Quality
Lisa R. Potoma, Quality Assurance
David M. Kluk, Laboratory Manager

NADCAP MATERIAL TESTING LABORATORY

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Edison Welding Institute
1250 Arthur E. Adams Drive
Columbus, OH 43221

Attn: Delores Suckow

Date: 1/20/99
Report No: 28355
P.O. No: 98-1995
Page 2 of 4

Client Description: **Carbon Steel**

NSL Lab No	Sample ID	Test	Results/Units
990000690	Job #40900CSP C		
		Al	0.022 %
		B	<0.0005 %
		C	<0.01 %
		Cb	<0.01 %
		Co	<0.05 %
		Cr	<0.10 %
		Cu	<0.05 %
		Mn	0.12 %
		Mo	<0.05 %
		Ni	<0.10 %
		P	0.007 %
		S	0.009 %
		Si	<0.10 %
		Sn	<0.01 %
		Ta	<0.10 %
		Ti	0.068 %
		V	<0.01 %
		W	<0.10 %
		Zr	<0.01 %

Reporting Officers

R04

Steven M. Podolan, Vice President Quality
Lisa R. Potoma, Quality Assurance
David M. Kluk, Laboratory Manager

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HTTP://www.nslanalytical.com

Edison Welding Institute
1250 Arthur E. Adams Drive
Columbus, OH 43221

Attn: [redacted]

Date: 1/20/99
Report No: 28355
P.O. No: 98-1995

Client Description: **Carbon Steel**

NSL Lab No	***Sample ID***	***Test***	***Results/Units***
990000689	Job #40900CSP		
	D	Al	0.025 %
		B	<0.0005 %
		C	<0.01 %
		Cb	<0.01 %
		Co	<0.05 %
		Cr	<0.10 %
		Cu	<0.05 %
		Mn	<0.10 %
		Mo	<0.05 %
		Ni	<0.10 %
		P	0.016 %
		S	0.009 %
		Si	<0.10 %
		Sn	<0.01 %
		Ta	<0.10 %
		Ti	0.073 %
		V	<0.01 %
		W	<0.10 %
		Zr	<0.01 %

Reporting Officers

R04

Steven M. Podolan, Vice President Quality
Lisa R. Potoma, Quality Assurance
David M. Kluk, Laboratory Manager

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ANALYSIS REQUISITION AND REPORT

3/29/99 ELC

PROJECT NO. AJZ73-35095

DESCRIPTION: AISP DDE Samples – Substrate Comp.

~~4/02/99~~ 4/1/99

SUBMITTED BY: P. Howe/C.F. Phelps | REQUESTED BY: P. Howe | DIVISION: HR Prod. | 9951 | BAD

LAB USE ONLY	SAMPLE IDENTIFICATION	DETERMINATIONS REQUIRED	C	Mn	P	S	Si	Al	Cu	Ni	Cr	V	Cb	Mo	Ti	B	N			
229 ST	C	Analysis Req'd.*																		
		Lab Analysis	[redacted]																	
		Report Values**	,0036	,17	,008	,009	,005	,033	,019	,019	,030	,002	<,005	,007	,070	<,0002	,0035			
230 ST	D	Analysis Req'd.*																		
		Lab Analysis	[redacted]																	
		Report Values**	,0030	,11	,014	,010	,014	,031	,013	,010	,026	,004	<,005	,004	,070	,0003	,0038			
231 ST	A	Analysis Req'd.*																		
		Lab Analysis	[redacted]																	
		Report Values**	,0035	,17	,007	,010	,005	,037	,021	,016	,027	<,002	,039	,006	,035	<,0002	,0034			
232 ST	B	Analysis Req'd.*																		
		Lab Analysis	[redacted]																	
		Report Values**	,0022	,10	,012	,008	,005	,052	,015	,012	,020	<,002	,007	,003	,044	<,0002	,0029			
		Analysis Req'd.*																		
		Lab Analysis	[redacted]																	
		Report Values**																		

SPECIAL INSTRUCTIONS: ELC 3/29

Poor repeats of B in sample 230ST. Result reported is average of 4 burns, ranging from 0 – .0003 B

PR OE CS N
118, 112, 111, 110

92061
ELC

Chemical Analysis Report

Bethlehem Steel Corporation
Homer Research Laboratories
Analytical Chemistry & Laboratory Services
1170 Eighth Avenue
Bethlehem, PA 18016

Requestor: P. Howe

Copies to:

Sample Description:
- **Source:** ASP DOE
- **Process:** Galvanneal
- **Type:** Coated Sheet Steel

Purpose of Request: Ct. Wt., %Al, %Fe

Report by: T. J. Moran

Signature:

Title: Material Coordinator

Phone Number: (610) 694 -6771

Date Reported: 04/05/99

Analysis Results

Coating weights reported as g/m^2, all other results reported as % (m/m)

	Ct. Wt. Side #1	Al Side #1	Fe Side #1	Ct. Wt. Side #2
A →	58.3	0.243	9.68	53.6
B →	51.9	0.238	10.0	56.6

Comments:

Test results relate only to the items tested.
Only signed reports are official.
Lab Serial No. 560

Chemical Analysis Report

Bethlehem Steel Corporation
Homer Research Laboratories
Analytical Chemistry & Laboratory Services
1170 Eighth Avenue
Bethlehem, PA 18016

Page 1 of 4

Requester: P. Howe

Copies to:

Sample Description:
Status: ASP DOE
Process: Hot Dip Galvanized
Type: Coated Sheet Steel

Purpose of Request: Ct. Wt., %Al, %Fe

Report by: T. J. Moser
Signature:
Title: Material Coordinator
Phone Number: (610) 694-6771
Date Reported: 04/02/99

Analysis Results
Coating weights reported as g/m², all other results reported as % (solid)

	Ct. Wt. Side #1	Al Side #1	Fe Side #1	Ct. Wt. Side #2
C →	71.6	0.445	0.422	74.8
D →	153.0	0.206	0.235	74.7

Post-it® brand fax transmittal memo 7671 | # of pages ▸ 3
To: Tom Mackie | From: Carter Hauck
Co.: EWI | Co.: Beth. Steel Corp
Phone #: 610-694-7851
Fax #: 614-[illegible]-1740 | Fax #: 610-694-2346

Comments: Sample 715 CO top was reported on a Best Effort Basis.
This sample exceeded the concentration range set by method CO-03A.

Note: This document is not to be reproduced, except in full, without written permission of Bethlehem Steel Corporation, Research Department

Test results relate only to the items tested.
Only signed reports are official.
Lab Serial No. 56050

Appendix D

DOE Data Collection Sheets

ASP DOE on Coated Steels

Site: EWI	Date:	Trial #:	Technician:

Initial Set-up Factor Level Settings

	Axa	Ana	CTyp	CTP	EGm	PF	CW	EP	EM	F (lbs)	EFT	FB	EGe

1st Exp. Current Level (Flexp) =	Exp. Current Level (Iexp) =	Actual Test Current Level =

DOE Trial Factor Level Settings

I (kA)	Axa	Ana	CTyp	CTP	EGm	PF	CW	EP	EM	F (lbs)	EFT	FB	EGe

Weld Button Data

Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 0							Set 4						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 1							Set 5						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 2							Set 6						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 3							Set 7						

Weld Button Data - Sheet 2													
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
796							1296						
797							1297						
798							1298						
799							1299						
800							1300						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
896							1396						
897							1397						
898							1398						
899							1399						
900							1400						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
996							1496						
997							1497						
998							1498						
999							1499						
1000							1500						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
1096							1596						
1097							1597						
1098							1598						
1099							1599						
1100							1600						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
1196							1696						
1197							1697						
1198							1698						
1199							1699						
1200							1700						

DOE Trial # Data Sheet 3

Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 18							Set 23						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 19							Set 24						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 20							Set 25						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 21							Set 26						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 22							Set 27						

Weld Button Data - Sheet 4

Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 28							Set 33						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 29							Set 34						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 30							Set 35						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 31							Set 36						
Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio	Weld #	I (kA)	Failure Mode	Min.	Max.	Avg.	Aspect Ratio
Set 32							Set 37						

Appendix E

Procedure Document Modifications

Prior to actually conducting the DOE electrode life trials, the experimental procedures used in this program have undergone numerous modifications. These modifications are the basis of "Operating Procedures for Conducting the A/SP DOE of Coated Steels – Drafts 1 through 8". These modifications were required based upon input from the A/SP Welding Committee and knowledge gained during the conduction of preliminary welding trials. The purpose of this Appendix is to document all of the modifications made to the Procedures Document and Experimental Program after the initiation of the electrode life testing.

1. **Fixtures**

    - During the initial welding trials associated with poor edge position it was determined that edge expulsion prevented ease of sample movement through the fixture. Each test location's fixture was modified such that the sample guides had removable front plates. Further, steel wear bars were added to prevent the materials from prematurely wearing out the guides.

2. **Section 1.1: Purpose of the Document**

    - Addition of the sentence, "As such, a secondary objective is to establish the procedures that will allow for proper tip dressing/stepper schedules to be developed.".

3. **Section 2.1: Welding Equipment**

    - "sustaining a welding rate of 25 to 30 welds/minute" was added to the last sentence of the paragraph.

4. **Section 4.2.2: Axial Electrode Alignment [Axial Alignment (AxA)]**

    - The following Note was added: "Some of the DOE welding trials require adjustment to both the axial alignment (AxA) and edge position (EP) factors. For these trials, the establishment of the edge position should be based upon the electrodes' position prior to adjusting for the AxA factor. In making the correct adjustment for the AxA factor, the adjustment is to be made such that the electrode being offset moves towards the centerline of the parent sheets."

5. **Section 4.2.8: Coating Weight (CW)**

    - Based upon the results of the composition and coating weight analysis, it was decided by the ASP DOE Committee to not distinguish two specifically different coating weights. In the text, specific identification of the materials as G60/G60, G98/G98, 45A/45A, and 60A/60A was removed. Appendix C was added to provide specific information on the parent materials, coating compositions, and coating weights. The previous Appendix C, ISO 669 was removed.

6. Section 4.2.13: Force Build-Up (FB)

- The following Note was added: "In determining the required squeeze times for each level of force build-up, in conjunction with each level of weld force, it may be determined that there is an insignificant difference in time (squeeze time) required to achieve two of the three levels. In such cases, modifications will be made to the levels of force build-up for that sight such that a more distinct difference is obtained.

7. Section 6.1: Initial Machine Set-up

- Removal of the sentence "The procedures followed here parallel those described for the Limit Test evaluations".

8. Section 8.0: Moving Forward

- Addition of Section 8.0