Experiment RSW

Resistance Spot Welding

Objective

The objective of this laboratory exercise is to examine the theoretical and experimental aspects of resistance welding. In this lab, a sample of steel sheet will be welded. The strength of the joint will be destructively tested using tensile testing machine.

In this lab, you will learn:

- Spot welding principles of operation
- Spot welding cycle and schedule
- Basic process parameters and how they affect welding process
- Weld inspection methods
- Mechanical and control systems of the welding machine.

Background

Resistance spot welding is a process in which faying surfaces are joined in one or more spots by resistance to the flow of electric current through workpieces that are held together under force by electrodes. The contacting surfaces in the region of current concentration are heated by a short-time pulse of low-voltage, high-amperage current to form a fused nugget of weld metal. When the flow of current ceases, the electrode force is maintained while the weld metal rapidly cools and solidifies. The electrodes are retracted after each weld, which usually is completed in a fraction of a second.

The size and shape of the individually formed welds are limited primarily by the size and contour of the electrode faces. The weld nugget forms at the faying surfaces, as shown in Figure 1, but does not extend completely to the outer surfaces. In section, the nugget in a properly formed spot weld is round or oval in shape; in plan view, it has the same shape as the electrode face (which is usually round) and approximately the same size. Spacing between adjacent spot welds or rows of spot welds must be enough to prevent shunting or to limit it to an acceptable amount.

![Figure 1. Spot Weld Illustration](image_url)

Spot Resistance Welding is widely used in joining sheet steel of thickness up to about .125 “ and can be used for many material including combinations of materials, refer to Appendix A for material weldability chart.. Many assemblies of two or more sheet-metal stampings that do not require gas-tight or liquid-tight joints can be more economically joined by high-speed resistance spot welding than by mechanical methods. Containers such as receptacles are spot welded. The attachment of braces, brackets, pads or clips to formed sheet-metal parts such as cases, covers, bases or trays is another common application of spot welding. One of the most important applications of resistance spot welding is in automotive industry-the car
frame body is constructed by spot welding of individual stamping parts, with manual portable welding guns, semi-automatic machines or fully automatic robots.

Major advantages of resistance spot welding are high speed and suitability for automation and inclusion in high-production assembly lines with other fabricating operations. With computer PLC control of current, timing and electrode forces, sound spot welds can be produced consistently at high production rates and low unit labor costs by unskilled operators.

Nomenclature:

I – current in Amperes
E – voltage drop across the electrodes in Volts
R – the resistance of the workpiece which is the sum of the contact, and material resistance to be welded in Ohms
H – total heat in watt-seconds (Joules)
T – time in seconds

Principle of Operation

The operation of spot welding involves a coordinated application of current of the proper magnitude for the correct length of time. This current must pass through a closed circuit. Its continuity is assured by forces applied to the electrodes, which are shaped to provide the necessary density of current and pressure. The entire sequence of operations is required to develop sufficient heat to raise a confined volume of metal, under pressure, to temperature must be such that fusion or incipient fusion is obtained, but not so high that molten metal will be forced from the weld zone. The rates of the rise and fall of temperature must be sufficiently rapid to obtain commercial welding speeds, but neither rate may be permitted to be so rapid that either inconsistent or brittle welds will be produced. The rates of rise and fall of temperature and the time of maintenance at temperature are determined by the characteristics of the metals being welded and by the capacity of available equipment.

The heat required for any resistance welding process is produced by the resistance offered to the passage of an electric current through the workpieces, in exactly the same manner as in any other electrical heating device. Since the electrical resistance of metals is low, high welding currents are required to develop the necessary welding heat. Typically the currents are in the range of 1000’s of Amps, while the voltage is at the level of a few Volts only.

The rate of heat generation depends upon the flow of current, in amperes, through the resistance offered by the materials. Other electrical factors, such as voltage, frequency and power factor, enter into consideration only with respect to their uniformity. They affect only the value of the current.

According to Ohm’s law,

\[ I = \frac{E}{R} \]  

(1)

where \( I \) is the current, \( E \) is voltage drop across the electrodes and \( R \) is the resistance through the material in ohms. \( R \) is the summation of the contact resistances and the resistance of the work to be welded. Therefore, for a given value of \( R \), the magnitude of \( I \) is determined by \( E \). Current to the primary of the transformer is controlled which, in turn, determines the current delivered to a weld of a given resistance. The total heat in watt-seconds generated in the work being welded and in the welding electrodes is expressed by the formula:

\[ H = I^2 RT \]  

(2)

or

\[ H = IET \]  

(3)

\( T \) is time in seconds.
Welding Cycle

The welding cycle is divided into four to five time segments: squeeze, preheat, weld, postheat, hold and off. These are shown in Figure 2. The time is expressed in cycles, where 1 second equals 60 cycles (60 Hz frequency of the AC voltage used).

*Squeeze time* is the time between the initial application of the electrode pressure on the work, and the first application of current in making spot weld. It provides time for the solenoid-actuated head cylinder valve to operate and for the welding head to bring the upper electrode in contact with the workpiece and develop full electrode force. For this lab this time is 60 cycles.

*Preheat* is a low current applied in the time interval before the full welding current is applied. Preheat is an optional segment. It reduces thermal gradients in the metal. The preheat step is not used in this lab.

*Weld time* is the interval during which the welding current flows through the circuit.

*Postheat time* is the interval during which current is on at a low level. It is used chiefly for grain refinement (tempering) on hardenable carbon and alloy steels. It is optional. For this lab it is 10 cycles at 20% power.

*Hold time* is the interval during which, after the welding current is off, the electrode force is held on the workpiece until the metal of the spot weld has solidified.

*Off time* is the interval from the end of the hold time until the beginning of the squeeze time for the next cycle. It is the time needed to retract the electrodes, remove or reposition workpiece.

All of the segments are usually expressed in cycles, meaning the number of cycles in a 60-cycle system, where one cycle is $\frac{1}{60}$ second.

![Figure 2. Welding Cycle](image)

Welding Schedules

A satisfactory weld depends on optimum setting of variables such as time, current and electrode force. Data recommended by the American welding Society for resistance spot welding of low-carbon, medium-carbon and low-alloy steels are available from suppliers. However, when experience is lacking, the most satisfactory conditions for spot welding has to be obtained through test. Following are steps to set up welding schedules:

*Make a preliminary selection of electrode force for the work to be used.* Ask the TA to provide starting points for making trial welds then verify or correct this preliminary selection of electrode force. Additional details related to process parameters are found in Appendix A.
Establish the weld time and hold time. This is done by evaluating trial welds made at several levels of current for each of a number of combinations of weld time and hold time. Squeeze time is not critical in welding trials and is usually set at a convenient value that is long enough to allow for a wide range of test conditions. 

Select electrode force. Using the established combination of weld time and hold time, make welds at several different current levels, using a number of values of electrode force to cover a wide range of force.

Select the welding current. Using the established weld time, hold time and electrode force, make test welds at current levels that cover a wide range of amperage.

Verify selection of conditions. Make trial runs under the welding conditions established by above steps, to verify these selections as well as to establish reference data on weld quality and reliability for use in process control.

Welding Test

The purpose of the test is to see how two important process parameters, the magnitude of current and the welding time, affect the strength of welded steel coupons. The change of current will be made through the change of percentage of preset maximum current and length of time through number of cycles. Other process parameters in welding schedule, such as electrode force, hold time and off time, etc are kept constant during the test.

System Configuration

The machine in the lab is composed of three components: the mechanical system, the PLC controller and the MedVIEW software interface, shown as Figure 3. MedVIEW and PLC controller form the control system coded MedWeld 3005.

![System Configuration Diagram]

Figure 3. System Configuration

The MedVIEW is Window based program that lets you program weld sequences or perform data acquisition from a central location. As a Microsoft Windows application, it provides the
point-and-click operation of a graphic interface. You can deposit up to 31 independent weld schedules in MedVIEW.

The PLC controller is an Allen-Bradley based control system with SLC-500 processor. A Medar weld processor is built in to provide firing signals to SCR which controls the current to the primary side of the transformer. A Medar modem is used to connect PC MedVIEW interface to the PLC controller.

The mechanical system is mainly composed of electrodes, electrode holders and clamping mechanism, a RoMan 575:5 transformer, a pneumatic cylinder providing double strokes controlled by two air valves, water cooling system for electrodes, air supply system and supporting frame. Electrode force transferred from the cylinder is adjusted through control valves in the valve box.

Procedure

Welding

1. Go to computer and load Medview program
2. Check “Weld Status” and then exit window
3. Click on “Program”
4. Select seq.001 and click on “Edit”
5. Edit command 20 to read WELD 10 CY, 40\%I
6. Click “Apply”
7. Save file and select “Yes” when prompted to download sequence to welder
8. Go to welder and ensure the “Control Stop” button is pressed in
9. Ensure the green “No Fault” light is on and the red “Alert” light is off
10. Lift protective shield
11. Place 2 strips of metal between the electrodes and close the shield
12. Ensure correct sequence is selected on welder (seq. 1)
13. Pull out “Control Stop” button (“Ready to Weld” light should come on)
14. Press “Weld Start” button
15. After welding is complete press in the “Control Stop” button
16. Lift shield and remove welded sample (Do not touch area near weld or electrode)
17. Repeat steps 2-16 for:
   1. 10 CY, 50\%I
   2. 10 CY, 60\%I
   3. 10 CY, 70\%I
   4. 10 CY, 80\%I
   5. 05 CY, 60\%I
   6. 20 CY, 60\%I
   7. 30 CY, 60\%I
   8. 40 CY, 60\%I
   9. 50 CY, 60\%I
18. Using suitable parameters, weld a sample in two adjacent locations. Ensure the welds are far enough apart to avoid shunting.

Tensile Test

1. Load the tensile test program on the computer (Labview)
2. Click on “Load VI” and select tensile test program.
3. Ensure both lights for zeroing the amplifier voltage are off (zeroed)
4. Place welded sample between the jaws of the tensile tester
5. Press the start button to initialize the machine.
6. Click the “Start” arrow in the program to begin data capture
7. Press UP button on tensile tester to start test
8. When the sample fractures, click on red “Stop” button on machine and stop the data capture in the program
9. Remove sample pieces from the machine
10. Use the down button and the speed control to return jaws to their original position as indicated.
11. Repeat steps 2-10 for each sample
12. Conduct one tensile test using an un-welded blank for purposes of comparison.

Results: Data Analysis and Discussion

For the data collected use the following calibration factor:

Load Cell: 1 volt = kg.

- Plot force versus time curves for each sample tested (appendix)
- Highlight both the ultimate and fracture strengths (forces) on each curve (record values on graph)
- Plot the ultimate strengths (forces) vs. both “current on time (cycles)” and “current (%I)” for all samples.
- Discuss results
  i. Describe the weld appearance, cause of failure, and identify the failure mode exhibited by each sample (i.e. brittle fracture, tearing)
  ii. Identify where fracture occurred for each sample (weld joint, heat affected zone, base metal)
  iii. Discuss the trends with respect to the effect of varying the weld current and time on the observed weld appearance, strength, and failure modes for the tests conducted.
  iv. Explain difference in the location of failure for each mode seen. (consider the un-welded blank and the double welded blank)
  v. Justify the trends observed in the experiment using the theory (do the results make sense?)

Recommended References

Important! Safety Awareness
Follow instructions included in the SOP – Spot Welder Laboratory included following this section.

1. THE OPERATION OF THE RESISTANCE WELDER HAS THE POTENTIAL TO DISRUPT THE OPERATION OF PACEMAKERS, DEFIBULATORS, OR SIMULAR DEVICES. ANY STUDENT WHO HAS ONE OF THESE DEVICES IS REQUIRED TO SEE THE PROFESSOR INCHARGE OF THE LAB TO MAKE ALTERNATE ARRANGEMENTS FOR THIS LAB AS SOON AS POSSIBLE.

2. DO NOT WEAR CONTACT LENS DURING THIS LAB. IF YOU ARE WEARING CONTACT LENS YOU WILL NOT BE ALLOWED TO PREFORM THIS LAB EVEN IF YOU ARE WEARING SAFETY GLASSES. T.A.'S DO NOT ALLOW UNDER ANY CIRCUMSTANCES ANY STUDENT WEARING CONTACT LENS TO PREFORM THIS LAB.

3. PROPER FOOTWEAR MUST BE WORN AT ALL TIMES (i.e. CLOSED TOE, AND CLOSED HEEL SHOES MUST BE WORN THIS MEANS SHOES LIKE SAFETY SHOES, BOOTS, RUNNING SHOES, ETC…NO SANDELS, CLOGS, OR SIMULAR FOOTWEAR. UNDER NO CIRCUMSTANCES WILL ANY STUDENT WEARING INPROPER FOOTWEAR BE ALLOWED TO PERFROM THIS LAB.

4. You must wear safety glasses during the test welding operation. Safety glasses are provided in lab.

5. Keep your hands clear from welding bench before actuating a welding operation on PLC control box, to prevent your hands from being clamped by electrodes accidentally. Students should not touch buttons on PLC controller without permission from TA.

6. Stand behind the safety line marked on the floor of the lab, unless operating the welder.

7. Touching hot workpiece can cause burns-always wear insulated gloves or allow a cooling period when touching these and any associated parts of equipment that are near the actual welding operation.

8. If something goes wrong during the welding sequence the system can be shut down using the “Control Stop” button.

9. It is recommended that participants in this lab do not wear polyester clothing.
MECHANICAL ENGINEERING UNDERGRADUATE LABORATORY
STANDARD OPERATING PROCEDURE (SOP)

Name of SOP | Spot Welder Laboratory  
Effective Date | March 30, 2004  
Author | M.P. Sklad/Jo Verhaeghe  
Reason for SOP | Risk of burn  
| Risk of eye injury  
| Risk of pinching body parts  
Approved by (supervisor) | Dr Ziada (Chair)  
Date reviewed by JHSC |  

Definitions
Terms | none  
acronyms | RMM – Risk Management Manual  
| JHSC - Joint Health and Safety Committee  

Requirements
Applicable OHSA regulations and / or codes of practice.
RMM – Eyeglass policy  
Training and competency.
Training provided by technical staff in the Mechanical Engineering Department. Competency is shown by the individual after training.

Description of the Task
Location and time of work | JHE314 during normal working hours  
Individuals and skills required | Graduate Students, none  
Equipment and supplies required | Spot Welder with Medar controller  
| Instron Model 1140  
Personal protective equipment required | Safety glass  
Sequential steps to complete the work safely.

General safety instructions
1. All users must obey the safety instructions and warnings posted on the welder.
2. The operator only should access the welder work area when the control stop button on the control panel is in pressed down position (the welder is off).
3. Never trigger the welding cycle without a sample of the material placed between the electrodes.
4. If the alert red light is on, press the Fault reset button. If the alert light stays on do not attempt to operate the welder and report the fault to the technicians in JHE205.

Operation of the welder:
1. Turn on the computer with the welding sequence programs and check whether the programs exist.
2. Turn on air supply  
3. Turn on water supply  
4. Push in the control stop button (welder off)  
5. Lift carefully the protective shield  
6. Place the sample between the electrodes  
7. Close the protective shield  
8. Unlock the power switch  
9. Turn the power on  
10. Pull out the control stop button (welder on)  
11. Select program sequence  
12. Set toggle switch “Weld/No weld” to the “Weld” position”  
13. Press “Weld Start” button  
14. Push in the stop control button (welder off)
15. Lift the protective shield and remove the sample avoiding touching the hot weld spot

**Operation of the Instron Tensile Machine:**

**Moving Crosshead Up or Down**
1. Ensure upper and lower stop are located correctly
2. Ensure everyone is clear of machine
3. Ensure correct speed is set (usually between 2 and 15)
4. Ensure MODE switch is set correctly.
5. Turn POWER switch to ON
6. Press “MOTOR AMPLIFIER START”
7. Press UP or DOWN button as required
8. Press STOP button to stop movement.
9. Turn POWER switch to OFF before making any adjustment to crosshead, jaw, inserting or removing specimen

**Tensile Test**
1. Ensure POWER is OFF
2. Set the lower crosshead stop to “TEST LOWER LIMIT”
3. Set the upper crosshead stop to “TEST UPPER LIMIT”
4. Turn POWER ON
5. Move crosshead to proper position to insert specimen. See instruction above “Moving Crosshead Up or Down”
6. Press “STOP” when crosshead reaches position
7. NOTE: At least 1/4 of the jaw should grab the specimen
8. Ensure POWER is OFF
9. Insert specimen and tighten jaws
10. Install extensometer if required
11. Adjust crosshead speed to 1
12. Move crosshead UP as required. See instruction above “Moving Crosshead Up or Down”

**Contingency Plan and Reporting**

**Accident / Injury response**
Minor cuts and bruises report to Technical staff, room JHE205, ext. 24628.

**In Case of Critical Injuries**
1. Shutdown equipment, secure area to prevent further injury
2. Immediately arrange for medical and emergency assistance by calling Security at “88”. Phone in JHE 316 (departmental office phone may be used)
3. Apply first aid as required
4. Notify Mechanical Engineering technical staff immediately
5. For all injuries complete a “Injury/Incident Report” and provide a copy to the Chair and EOHSS
6. In case of critical injury notify EOHSS immediately, ext 24352

**Spill response**

**Equipment shutdowns.**
1. Push in the stop control button (welder off)
2. Turn off the water
3. Turn off the air
4. Turn off the power
5. Lock the power switch
6. Turn off POWER switch on Instron 1140

**Environmental Responsibility**
MECHANICAL ENGINEERING UNDERGRADUATE LABORATORY
STANDARD OPERATING PROCEDURE (SOP)

<table>
<thead>
<tr>
<th>Waste disposal procedures</th>
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</thead>
<tbody>
<tr>
<td>Deposit used sample in recycle bin</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building air quality</th>
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</thead>
<tbody>
<tr>
<td>Procedure does not effect air quality</td>
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</table>

**References** (OHSA/ regulations, EPA and Municipal environmental regulations, McMaster University Program/ Policy, Material Data Sheets (MSDS)).

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1.</td>
<td>RMM #301 Standard Operating Procedure</td>
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<td>2.</td>
<td>RMM #300 Safety Orientation and Training Program</td>
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<td>3.</td>
<td>RMM #310 Eye Protection</td>
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<td>4.</td>
<td>RMM #309 Laboratory safety manual</td>
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**Distribution**

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<tbody>
<tr>
<td>1.</td>
<td>Trained teaching assistant who is the lab operator</td>
</tr>
<tr>
<td>2.</td>
<td>Technical Staff of Mechanical Engineering</td>
</tr>
<tr>
<td>3.</td>
<td>Mechanical Engineering Chair</td>
</tr>
<tr>
<td>4.</td>
<td>Faculty of Engineering JHSC</td>
</tr>
</tbody>
</table>
APPENDIX A
DATA SHEET

RECOMMENDED ELECTRODE MATERIALS

The process of resistance welding makes it possible to join most metals, similar or dissimilar. Bonds of adequate strength are obtainable for an extremely wide range of applications. Selection of the proper alloy has most important place in producing sound joints at the lowest cost. The chart below is available guide for this selection.

The metals listed are in most cases the following chart has been developed for identification of the various types of materials and to provide information on their weldability. The chart includes:

Electrode Materials For SPOT WELDING Similar and Dissimilar Metals

<table>
<thead>
<tr>
<th>Commercially Pure Titanium</th>
<th>Commercially Pure 25% AI</th>
<th>Commercially Pure 80% AI</th>
<th>Commercially Pure 25% AI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ti-6AI-4V</td>
<td>2. Ti-6AL-4V</td>
<td>3. Ti-5AL-2.5Sn</td>
<td>4. Ti-5AL-2.5Sn</td>
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<tr>
<td>5. Ti-6AL-2Sn</td>
<td>6. Ti-6AL-2Sn</td>
<td>7. Ti-6AL-2Sn - Type 6</td>
<td>8. Ti-6AL-2Sn - Type 6</td>
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Block Interpretation

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<tr>
<th>WELDABILITY</th>
<th>ELECTRODE AGAINST</th>
<th>ELECTRODE AGAINST</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Excellent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B - Very Good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C - Good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D - Fair</td>
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</tbody>
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SPECIAL INFORMATION

1. Good weld strength
2. May be welded under special conditions
3. Low weld strength
4. Welding equipment is not required
5. Welding equipment is required for welding
6. Welding equipment is not required for welding
7. Welding equipment is not required for welding
8. Welding equipment is required for welding
9. Welding equipment is required for welding

10. No post-welding heat treatment is required
11. Post-welding heat treatment is required for welding
12. Post-welding heat treatment is required for welding

Electrodes

1. CRMP-25
2. CRMP-15
3. EL-ROM-15
4. EL-ROM-15
5. EL-ROM-15
6. EL-ROM-15

Metal Alloys

1. Stainless Steel
2. Alloy Steel
3. Copper
4. Brass
5. Bronze
6. Aluminum
7. Magnesium
8. Titanium

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14. Post-welding heat treatment is required for welding
15. Post-welding heat treatment is required for welding

16. No post-welding heat treatment is required
17. Post-welding heat treatment is required for welding
18. Post-welding heat treatment is required for welding
19. No post-welding heat treatment is required
20. Post-welding heat treatment is required for welding

133