**Session 12-13**

# Assessment of Effect of Resistivity in Resistance Butt Welding of Wire Rods

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## Abstract

Butt welding of wire rods is an essential requirement for continuous wire drawing process. This research assesses how the knowledge of resistivity of a particular wire rod helps in selecting the welding parameters and optimizes the power to obtain a good weld. Tensile strength, cracks and porosity, inclusions, flash characteristics, length of HAZ, and martensite content of welds were determined in wire rods of two different grades of steel (with high and low resistances) welded with selected combinations of welding variables. The work was carried out in association with Gerdau Ameristeel, Beaumont (GAB) at their plant. The main observations made in this work are summarized below.

In general better tensile strength is obtained when wire rods of higher resistivity are welded, while larger amount of flash to flush away inclusions, less weld cracks, smaller HAZ and lower amount of martensite in HAZ are obtained when wire rods of lower resistivity are welded. The higher resistance wire rods are better welded with the higher heat settings (in this research it was setting '2') and the lower resistance wire rods with a lower heat settings (in this research it was setting '4'). When the higher and the lower resistance wire rods are welded together the voltage setting is governed by the requirement of the lower resistance wire rod.

## Introduction

To meet market demand most industries try to increase productivity but maintaining the quality of the product when a large variety of materials come into play becomes a difficult job. An increase in productivity sometimes causes some defective products which if found in an assembly line, may cause the whole batch to be rejected. In the wire industry it often necessary to switch to a different wire to make a variety of wire meshes. For this purpose welding of different wire rods is necessary for continuous production of the wire needed for wire mesh. Different wire rods depending upon material and geometry will need welding parameter adjustments. To find out how these parameters need to be adjusted to produce good welds, Lamar University in collaboration with Gerdau Ameristeel Beaumont[8] (GAB) set out to develop a tool to adjust different welding parameters on the basis of wire rod resistivity.

The hypothesis governing the present research is as follows. For given contact pressure and cooling conditions, the amount of heat produced in resistance butt welding is directly related to resistance of the wire rod which is dependent on resistivity. Thus, knowledge of resistivity of wire rods will provide vital information regarding weld parameters required for good welds.

Resistance welding is a process by which two different materials are joined by the application of heat and pressure. A current generated by a transformer passes through electrodes which hold the metal piece. These current then reacts with the local resistances to produce heat. The electrode serves a dual function of supplying current as well as the pressure to hold the metal pieces together[6]. As resistance across the joint is small, large amounts of currents are required. In resistance welding it is most important to control the heat generated in order to precisely controlling the current flow as well as contact forces and cooling of system components.

This project sponsored by GAB had the following goals: (a) check the quality of weld in general practice at GAB for welding of wire rods, (b) establish how weld parameters need to be adjusted on the basis of resistivity of wire rod[1], to improve the quality of weld of wire rod. The quality was assessed through the study of tensile behavior, microstructure of the heat affected zone (HAZ), microstructural features of the weld such as inclusions and porosity and the extent and geometry of flash[6].
Heat Affected Zone (HAZ) is the region affected by the heat of the weld[8]. HAZ lies just next to fusion zone and its temperature is just below the solidus temperature. Length of HAZ depends on cooling rate. Temperature in association with time plays important role in alteration of microstructure of metal in HAZ and for that to happen there should be a phase change [6,8,10].

Resistivity measures how much a material opposes the current flowing through it. It is defined as the resistance of unit area of the material per unit length[11]
The resistivity ‘ρ’ is an intrinsic property of a material[11] is given by:

$$\rho = R*A/L$$

where ‘L’ is the length of the wire, ‘A’ is its cross-sectional area and R is the resistance.

## Experimental Procedure

1. Three types of welds were considered for this project.
    - 1.1 Weld produced by using general practice at GAB.
    - 1.2 Weld produced by modifying parameter (voltage and resistance) i.e. Voltage below and above general practice.
    - 1.3 Weld produced by using different types of wire rod (difference is in resistance).
2. Material selection: two grades of low carbon steel, NS 1018-3and 1008 COS-3 were selected.
3. Geometry of wire rod: the wire rods selected for measurement of resistance were 14” long; those selected for welding purposes were 6” long. The rods had 7/32” diameter.
4. Measurement of resistance of wire rods using a nanovolt micro-ohm meter: ASTM standard B193-00[2] was strictly followed for resistance measurement. Five samples of each rod were randomly selected to measure the resistance.
5. Selection of butt welder: J6S butt welder manufactured by the Micro Product Company9.
6. Input variables: a) Voltage
   b) Resistance

In Table 1 are shown the chemical compositions of the two grades of wire rods used in the experiments.

Table 1. Chemical Composition of Selected Materials

| Chemical | Grade |
|---|---|

| | NS1018-3 | 1008 COS-3 |
|---|---|---|
| C | 0.187 | 0.060 |
| Mn | 0.650 | 0.420 |
| P | 0.006 | 0.014 |
| S | 0.008 | 0.020 |
| Si | 0.210 | 0.110 |
| Cu | 0.190 | 0.110 |
| Ni | 0.090 | 0.060 |
| Cr | 0.070 | 0.050 |
| Mo | 0.016 | 0.000 |
| V | 0.001 | 0.005 |
| Sn | 0.011 | 0.002 |
| Cb | 0.000 | 0.000 |
| N | 0.010 | 0.008 |

In Table 2 are shown the resistance and resistivity of the wire rods used.

Table 2. Resistance and Resistivity of Selected Wire Rods

| Grade | Resistance in Ω ( of 12 inch rod ) | Resistivity in μ-Ω-m |
|---|---|---|
| 1008 COS-3 | 0.0021316 | 0.1749 |
| NS1018-3 | 0.0025433 | 0.2088 |

**Welding of Wire Rod**

The welding experiments were divided into three groups and ten samples were used for each run. All samples were cleaned and their ends were flattened and smoothed as much as possible and then the butt welder was set. A 1:1 hydrochloric bath was used to remove scales on wire rod. Use predefined Voltage setting. The butt welder has 6 heat settings. GAB uses a heat setting of '3' for daily production. In these experiments we consider heat setting '2' and heat setting '4' as high and low heat settings respectively. Upset pressure and initial gap distance between two clamps and other welding parameter were kept unchanged. Upset pressure and gap distance were selected as per the service manual[9] of the butt welder. For this experiment, the voltage of each heat setting was assumed constant and its value was obtained from the butt welder manufacturer. In Table 3 are shown the details of heat setting and associated voltage values.

Table 3. Heat Setting and Associated Voltage

| Heat setting | Voltage in 'Volt' | Symbol used in experiment |
|---|---|---|

| | | |
|---|---|---|
| 1 | 3.34 | V1 |
| 2 | 2.94 | V2 |
| 3 | 2.50 | V3 |
| 4 | 1.92 | V4 |
| 5 | 1.48 | V5 |
| 6 | 1.20 | V6 |

In Tables 4, 5, 6 are shown the voltage settings used in the present experiments. Here,
RL = low resistance wire rod (1008COS-3).
RH = high resistance wire rod ( NS1018-3).

Table 4. Experiment 1

| Run | Resistance | Voltage |
|---|---|---|
| 1 | RL+RL | V3 |
| 2 | RH+RH | V3 |
| 3 | RL+RH | V3 |

Table 5. Experiment 2

| Run | Resistance | Voltage |
|---|---|---|
| 1 | RH+RH | V2 |
| 2 | RH+RH | V4 |
| 3 | RL+RL | V2 |
| 4 | RL+RL | V4 |

Table 6. Experiment 3

| Run | Resistance | Voltage |
|---|---|---|
| 1 | RH+RL | V2 |
| 2 | RH+RL | V4 |

In Figure 1 is shown a view of a resistance butt welded sample.

Figure 1. Resistance Butt Welded Sample

**Tensile Strength of Weld**
Tests were performed according to ASTM standard[4] in a universal testing machine.

**Preparation of Metallographic Sample**
ASTM standard E3-95[3] was strictly followed for sample preparation.

## Test Results and Discussion

The following analysis was conducted on the weld samples.
1. Observation of flash characteristics.
2. Tensile test.
3. Metallographic analysis.
    - Qualitative assessment of martensite in weld.
    - Qualitative assessment inclusion[5] and their flow.
    - Qualitative assessment of cracks and shrinkage.
    - Measurement of HAZ

**Observation of Flash Characteristics**
All flash had good appearance except for a few.
All the roots of segmented part of flash had formed a solid ring, i.e. they did not touch the surface of the rods. Range of flash area is from 0.25 to 0.54 Sq.in.
In Figure 2 is shown a view of flash appearance due to insufficient heat.

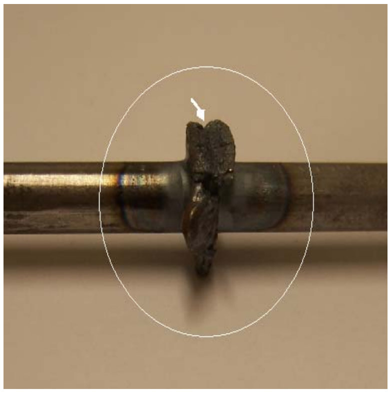

Figure 2. Flash Appearance due to Insufficient Heat

In Table 7 are shown the values of average flash area obtained after welding. It is seen that larger flash area is obtained when wire rods of lower resistivity are welded. Larger flash area helps I better flushing of the inclusions.

Table 7. Average Flash Area

| Weld sample | Heat setting | Avg. Flash Area (sq.in) |
|---|---|---|

| | | |
|---|---|---|
| RH + RH | 3 | 0.38 |
| | 2 | 0.39 |
| | 4 | 0.34 |
| RL + RL | 3 | 0.42 |
| | 2 | 0.45 |
| | 4 | 0.39 |
| RH + RL | 3 | 0.39 |
| | 2 | 0.36 |
| | 4 | 0.34 |

**Tensile Test**

For tensile test, strength of the samples was checked before experiment was conducted as the samples used for experiments were produced around two month earlier. This accounted for any increase in strength due to aging.

In Table 8 are shown the values of the tensile strength obtained after welding. It is seen that higher tensile strengths are obtained when wire rods of higher resistivity are welded.

Table 8. Tensile Strength of Weld Sample

| Weld sample | Heat setting | Avg. Strength (psi) |
|---|---|---|
| RH + RH | 3 | 81026 |
| | 2 | 80861 |
| | 4 | 79905 |
| RL + RL | 3 | 61632 |
| | 2 | 60566 |
| | 4 | 62116 |
| RH + RL | 3 | 61683 |
| | 2 | 62602 |
| | 4 | 62554 |

**Qualitative Assessment of Martensite**[10]

In Table 9 is shown the percentage of martensite as a fraction of the HAZ. It is seen that lower percentage of martensite is obtained when wire rods of lower resistivity are welded. Lower martensite content reduces the tendency for HAZ cracking.

Table 9. Percentage of Martensite in HAZ.

| sample ID | Mold | Flash | No | Sample | Heat No | % Martensite in HAZ |
|---|---|---|---|---|---|---|
| A | 1 | L | 2 | RH + RH | 4 | 32 |
| B | 1 | H | 7 | RH + RH | 4 | 40 |
| C | 1 | L | 10 | RH + RH | 2 | 63 |
| D | 2 | H | 2 | RH + RH | 2 | 73 |
| E | 2 | H | 10 | RH + RH | 3 | 57 |
| F | 2 | L | 3 | RH + RH | 3 | 54 |
| G | 3 | L | 7 | RH + RL | 4 | 50 |
| H | 3 | H | 1 | RH + RL | 4 | 60 |
| I | 3 | L | 1 | RH + RL | 3 | 58 |
| J | 4 | H | 10 | RH + RL | 3 | 60 |
| K | 4 | H | 9 | RH + RL | 2 | 64 |

| | | | | | | |
|---|---|---|---|---|---|---|
| L | 4 | L | 6 | RH + RL | 2 | 55 |
| M | 5 | L | 8 | RL + RL | 3 | 0 |
| N | 5 | H | 4 | RL + RL | 3 | 0 |
| O | 5 | L | 7 | RL + RL | 4 | 0 |
| P | 6 | H | 10 | RL + RL | 4 | 0 |
| Q | 6 | H | 10 | RL + RL | 2 | 0 |
| R | 6 | L | 3 | RL + RL | 2 | 0 |

**Metallographic Analysis: Qualitative Assessment of Inclusions and Their Flow**
ASTM standard E45[5] was followed for analysis of inclusion. Though there is a presence of inclusion in every sample, the amount of inclusion found was within the acceptable range as per ASTM standard E45-05.Most of these inclusions were driven out by the flashes. Almost all inclusions were of globular type with only two samples having sulphide inclusion. In Figure 3 is shown a view of sulphide inclusion in a weld sample. Figure 4 shows a view of appearance of void and inclusion in a weld.

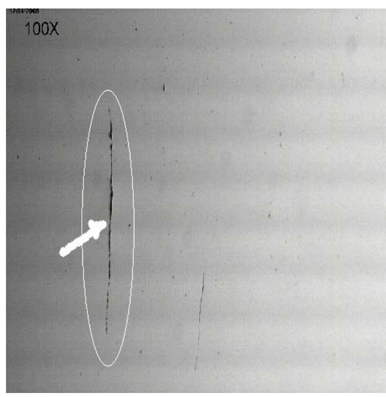


Figure 3. Sulphide Inclusion in Weld Sample

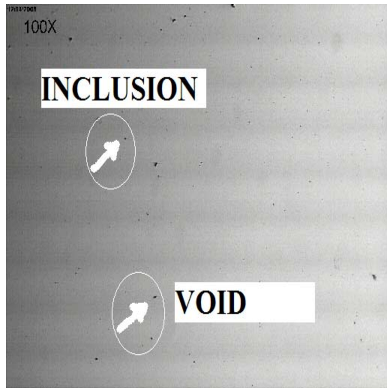


Figure 4. Inclusion and Void in Weld.

**Metallographic Analysis: Qualitative Assessment of Cracks and Porosity due to Shrinkage**
Probable reasons for porosity and crack formation are:

1. Austenite-martensite transformation.
2. Heterogeneous heating and cooling.

In Table 10 are shown the fraction of cracks in HAZ after welding. Figure 5 shows a view of cracks and porosity in a welded sample. It is seen that crack percentage is lower when wire rods of lower resistivity are welded.

Table 10. Percentage of Cracks in Weld Sample

| Sample ID | Sample | Heat No | % crack in HAZ area |
|---|---|---|---|
| A | RH + RH | 4 | 2.28 |
| B | RH + RH | 4 | 3.74 |
| C | RH + RH | 2 | 0.00 |
| D | RH + RH | 2 | 0.42 |
| E | RH + RH | 3 | 1.63 |
| F | RH + RH | 3 | 0.53 |
| G | RH + RL | 4 | 0.77 |
| H | RH + RL | 4 | 0.99 |
| I | RH + RL | 3 | 0.59 |
| J | RH + RL | 3 | 0.77 |
| K | RH + RL | 2 | 0.18 |
| L | RH + RL | 2 | 0.16 |

| | | | |
|---|---|---|---|
| M | RL + RL | 3 | 0.19 |
| N | RL + RL | 3 | 0.00 |
| O | RL + RL | 4 | 0.15 |
| P | RL + RL | 4 | 0.23 |
| Q | RL + RL | 2 | 0.04 |
| R | RL + RL | 2 | 0.20 |

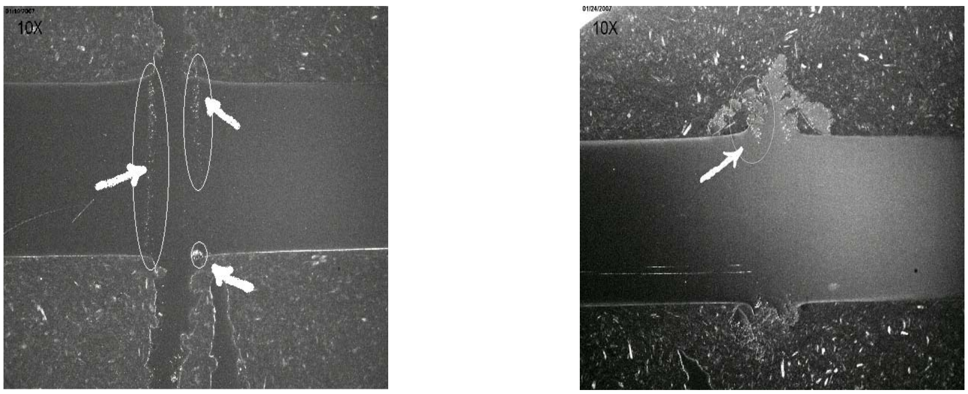


Figure 5. Cracks and Porosity in Weld Sample

**Metallographic Analysis: Measurement of Length of HAZ**

Figure 6 shows a view of the sample used for metallographic examination of samples to determine HAZ length and fraction of cracks. In Table 11 are shown the measured values of HAZ length. It is seen that the length of HAZ is less when wire rods of lower resistivity are welded.


Figure 6. Sample Prepared for Metallographic Analysis

Table 11. Measurement of Length of HAZ

| Sample ID | Sample | Heat No | HAZ in inches |
|---|---|---|---|
| A | RH + RH | 4 | 0.43 |
| B | RH + RH | 4 | 0.43 |
| C | RH + RH | 2 | 0.41 |
| D | RH + RH | 2 | 0.41 |
| E | RH + RH | 3 | 0.42 |
| F | RH + RH | 3 | 0.36 |
| G | RH + RL | 4 | 0.38 |
| H | RH + RL | 4 | 0.38 |
| I | RH + RL | 3 | 0.36 |
| J | RH + RL | 3 | 0.37 |
| K | RH + RL | 2 | 0.36 |
| L | RH + RL | 2 | 0.48 |
| M | RL + RL | 3 | 0.36 |
| N | RL + RL | 3 | 0.37 |
| O | RL + RL | 4 | 0.37 |
| P | RL + RL | 4 | 0.39 |
| Q | RL + RL | 2 | 0.35 |
| R | RL + RL | 2 | 0.37 |

## Summary

1. In general better tensile strength is obtained when wire rods of higher resistivity are welded, while larger amount of flash to flush away inclusions, less weld cracks, smaller HAZ and lower amount of martensite in HAZ are obtained when wire rods of lower resistivity are welded.
2. The higher resistivity wire rods are better welded with the higher heat settings [in this research it was setting ‘2’ (2.94V)] and the lower resistivity wire rods with a lower heat settings [in this research it was setting ‘4’ (1.92V)].
3. When the higher and the lower resistance wire rods are welded together the voltage setting is governed by the requirement of the lower resistance wire rod.

4. A flash area of 0.26 to 0.54 sq.in as observed in the present experiments results in levels of inclusions acceptable to the industry, indicating that the welding environment at Gerdau Ameristeel Beaumont (GAB) is good.

## Acknowledgement

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