Selective Oxidation of Advanced High Strength Steels (AHSS) and Ultra High Strength Steel (UHSS) Utilizing Direct Fired Burners

Scott Brown[1], David Schalles[2], Frank Beichner[3]

[1]Director of Sales and Business Development
Bloom Engineering Company, Inc.
5460 Horning Road, Pittsburgh, PA 15236
sbrown@bloomeng.com
330-730-0096

[2]Vice President of Technical Services
Bloom Engineering Company, Inc.
5460 Horning Road, Pittsburgh, PA 15236
dschalles@bloomeng.com
412-653-3500

[3]Vice President of Engineering
Bloom Engineering Company, Inc.
5460 Horning Road, Pittsburgh, PA 15236
fbeichner@bloomeng.com
412-653-3500

Key words: Selective Oxidation; Direct Fired Burners; Hot Dip Galvanizing Line; HDGL; Wettability; Retrofit; New Installation

ABSTRACT

This paper will address the utilization of direct fired burners for the production of Advanced High Strength Steel (AHSS) and Ultra High Strength Steel (UHSS) utilizing the selective oxidation process. The paper will concentrate on Hot Dip Galvanizing Lines (HDGLs) to show how to implement the selective oxidation process, utilizing direct fired burners, to increase the wettability of the steel in the zinc coating pot as well as physical properties of the steel. The process discussed will include placement of the selective oxidation zone in the furnace, combustion set-up needed to perform the process, as well as common process parameters. This paper will also discuss the way that new and current Hot Dip Galvanizing Lines (HDGLs) can be built or retrofitted to allow for the selective oxidation process, utilizing direct fired burners.

INTRODUCTION

The main driving force behind the Advanced High Strength Steel (AHSS) and Ultra High Strength Steel (UHSS) is the constant change of the Automotive Industry both domestically in the United States as well as globally. The use of Advanced High Strength Steel (AHSS) and Ultra High Strength Steel (UHSS) allows the material to have high formability as well as increase in the strength of the steel, while at the same time reduce the weight of the overall vehicle. The overall lessened vehicle weight allows for greater fuel efficiency and the reduction of emissions into the atmosphere.

There is a great need to be able to convert existing Hot Dip Galvanizing Lines to be able to process Advanced High Strength Steel (AHSS) and Ultra High Strength Steel (UHSS) as well construct new process lines to bring additional capacity to market. By being able to use selective oxidation with direct fired burners to process Advanced High Strength Steel (AHSS) and Ultra High Strength Steel (UHSS) capital equipment costs and operational costs can be limited. The steel can also be produced more quickly.

MAIN BODY PAPER

The main driver for the need for AHSS and UHSS is the automotive industry that requires greater fuel efficiencies in the future. The use of AHSS and UHSS allows the material to have high formability as well as being stronger than standard steels. With the formability and strength being high, the amount of steel needed for the automobile can be reduced, thus leading to improved fuel efficiencies.

It is anticipated that there will be 110 million automobiles produced, globally, by the year 2020. (Roughly 91.5 million vehicles were produced in 2015)

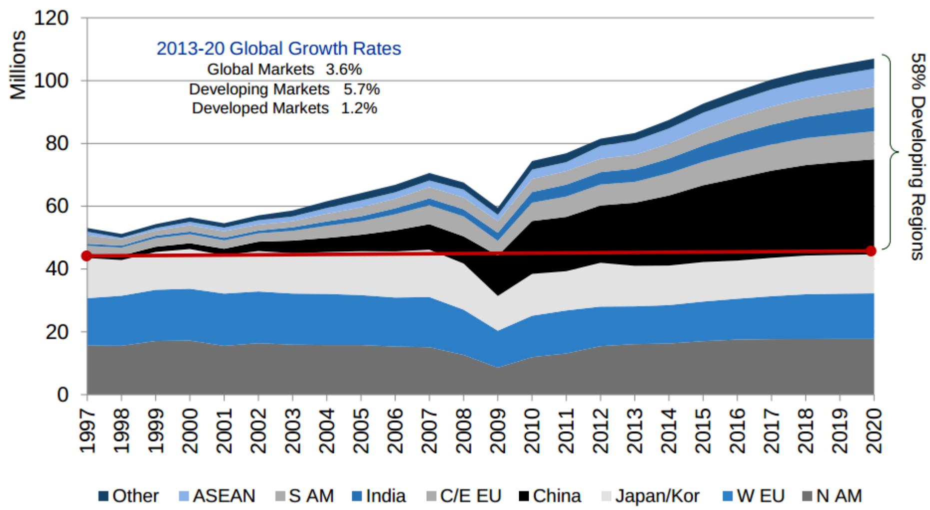

Figure 1 – Anticipated Volume of Automobiles Until Year 2020

Further, it is anticipated that the amount of AHSS and UHSS on an average per automobile basis will more than triple to 450 pound per automobile in the year 2020.

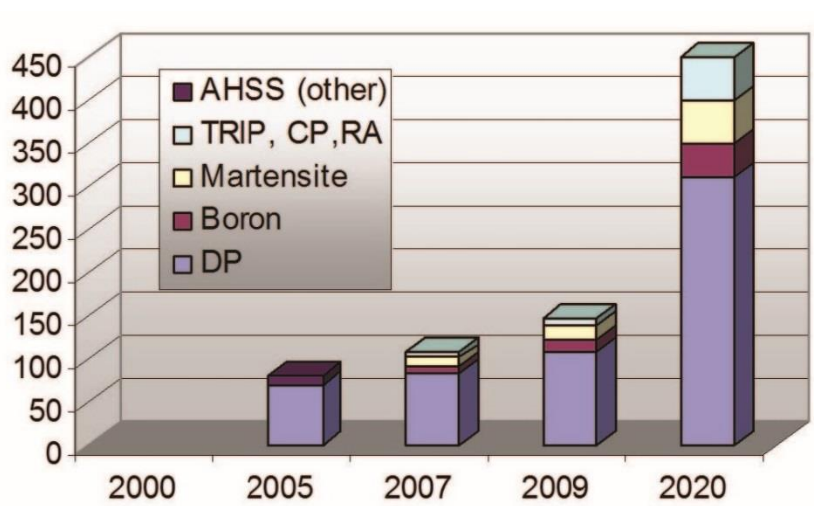

Figure 2 – Anticipated Amount of AHSS & UHSS Used in Automobiles until Year 2020

Judging from the above figures, there is a real need in the market to have the equipment be installed on existing process lines as well as new installations to produce AHSS and UHSS.

The remainder of this paper will be discussing the use of direct fired burners for the selective oxidation process, estimated process parameters, and the basic inter-workings of the process to be able to produce high strength steels.

The AHSS and UHSS, when speaking about automobiles is often referred to collectively as 3rd Generation AHSS material that processes both high tensile strengths as well as low percentages of elongation, as can be seen from the Global Formability Diagram in Figure 3 below.

AHSS are generally defined as having tensile strengths greater than 550 MPa. UHSS are generally defined as having tensile strengths greater than 780 MPa.

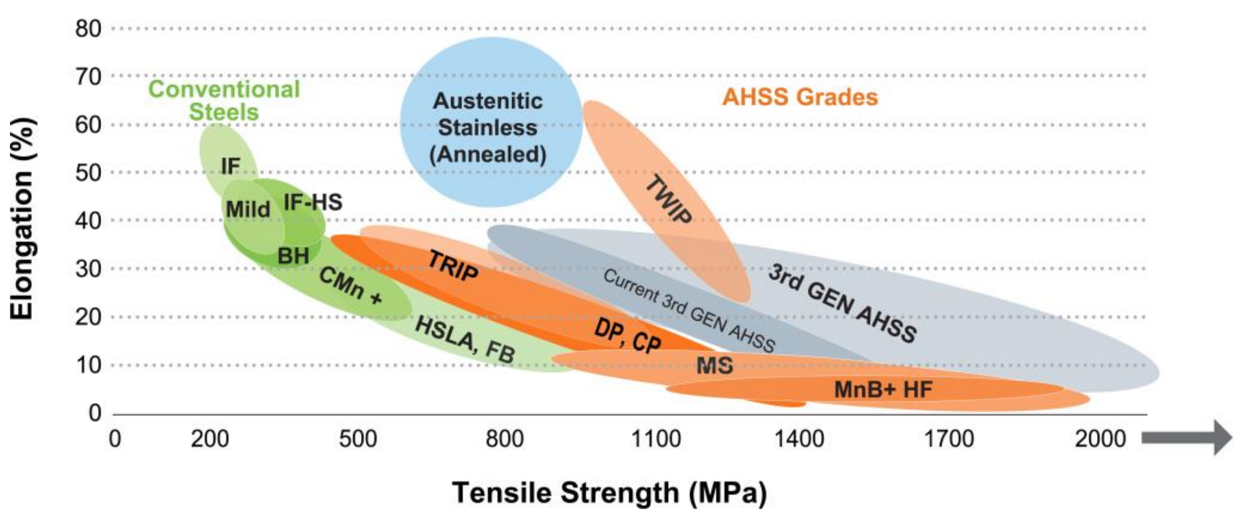

Figure 3 – Global Formability Diagram for AHSS & UHSS Steels

When processing AHSS and UHSS, the chemistry of the steel contains elements that are not part of standard steel chemistries, or these elements are in very small amounts. Elements that are part of AHSS and UHSS are Silicon (Si), Manganese (Mn), Aluminum (Al), Chromium (Cr) and Boron (B).

The use of direct fired selective oxidation is best when steel chemistries have Silicon (Si) content of greater than .5% and up to as high as 3%. Also, direct fired selective oxidation works best with Manganese (Mn) chemistries of 5% to 6%.

When processing the high strength steels, non-wettable oxides are created on the surface of the steel strip. The main non-wettable oxides created are Manganese Oxide (MnO), Silicon Oxide (SiO_2) and Manganese-Silicon Oxide ($MNnO_3$). These oxides, as well as some minor other precipitate to the surface of the strip and create cases where there is non-adherence of Zinc in the coating pot or bare spots on the strip (See Figure 4).

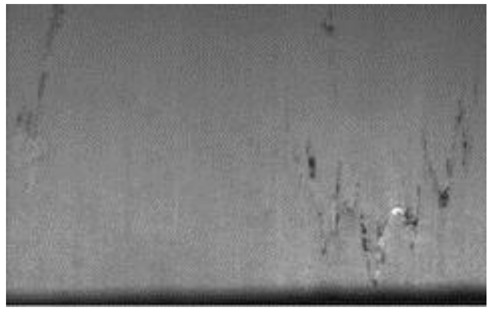

Figure 4 – Bare Spots on AHSS Material Due to Oxides

When processing "standard steels" on a Hot Dip Galvanizing Line with either a Direct Fired Furnace (DFF) or Non-Oxidizing Furnace (NOF) the air to gas ratio (or λ) is kept at a range of approximately .90 to .95, or 90 to 95 percent perfect combustion. The reason for this ratio is that with a gas rich process atmosphere, the reducing components of hydrogen (H_2) and Carbon Monoxide (CO) clean the steel of residual rolling oils, iron fines, and smut. The reminder of the Hot Dip Galvanizing Line is usually equipped with a Radiant Tube Furnace for final heating and soaking. These sections are also under a reducing atmosphere of between 5% to 15% Hydrogen (H2) and balance Nitrogen to further reduce any remaining oxides on the strip prior to entry into the coating bath.

When utilizing a Direct Fired Furnace (DFF) or Non-Oxidizing Furnace (NOF) for the use of selective oxidation, the purpose is to rapidly heat the high strength steels to trap the non-wettable oxides in a layer of iron oxide (FeO). The iron oxide (FeO) layer is accomplished by rapid heating of the steel strip in a process atmosphere that is oxidizing with a $\lambda > 1.0$ (Figure 5).

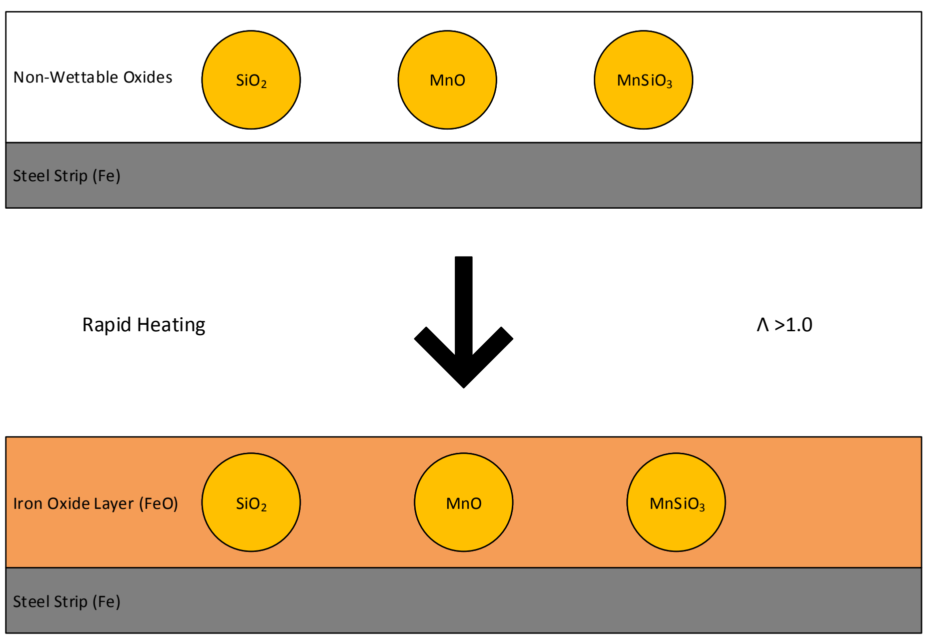

Figure 5 – Pictorial of Iron Oxide (FeO) Layer Trapping Non-Wettable Oxides

After the Direct Fired Furnace (DFF) or Non-Oxidizing Furnace (NOF), the steel strip is then processed through the radiant tube section as well as the reducing section. Again, these sections operate in the range of 5% to 15% Hydrogen (H_2) and balance Nitrogen to reduce away the Iron Oxide (FeO) layer and the non-wettable oxides are driven back into the steel strip prior to strip coating. The above selective oxidation process allows for good coating of the strip with no bare spots and non-coated areas.

With the overall process discussed above, we now turn to the implementation of the selective oxidation process in the Hot Dip Galvanizing Line. The selective oxidation process will work in either a horizontal or vertical configuration of the galvanizing furnace.

The selective oxidation should occur in the final zones of the DFF or NOF. Ideally, if all furnace zones are identical in length, the final furnace zones should be split into two smaller zones to allow for the utmost control of the oxidation layer in the furnace. Below is a pictorial of a “common” Direct Fired Furnace arrangement, in a vertical furnace.

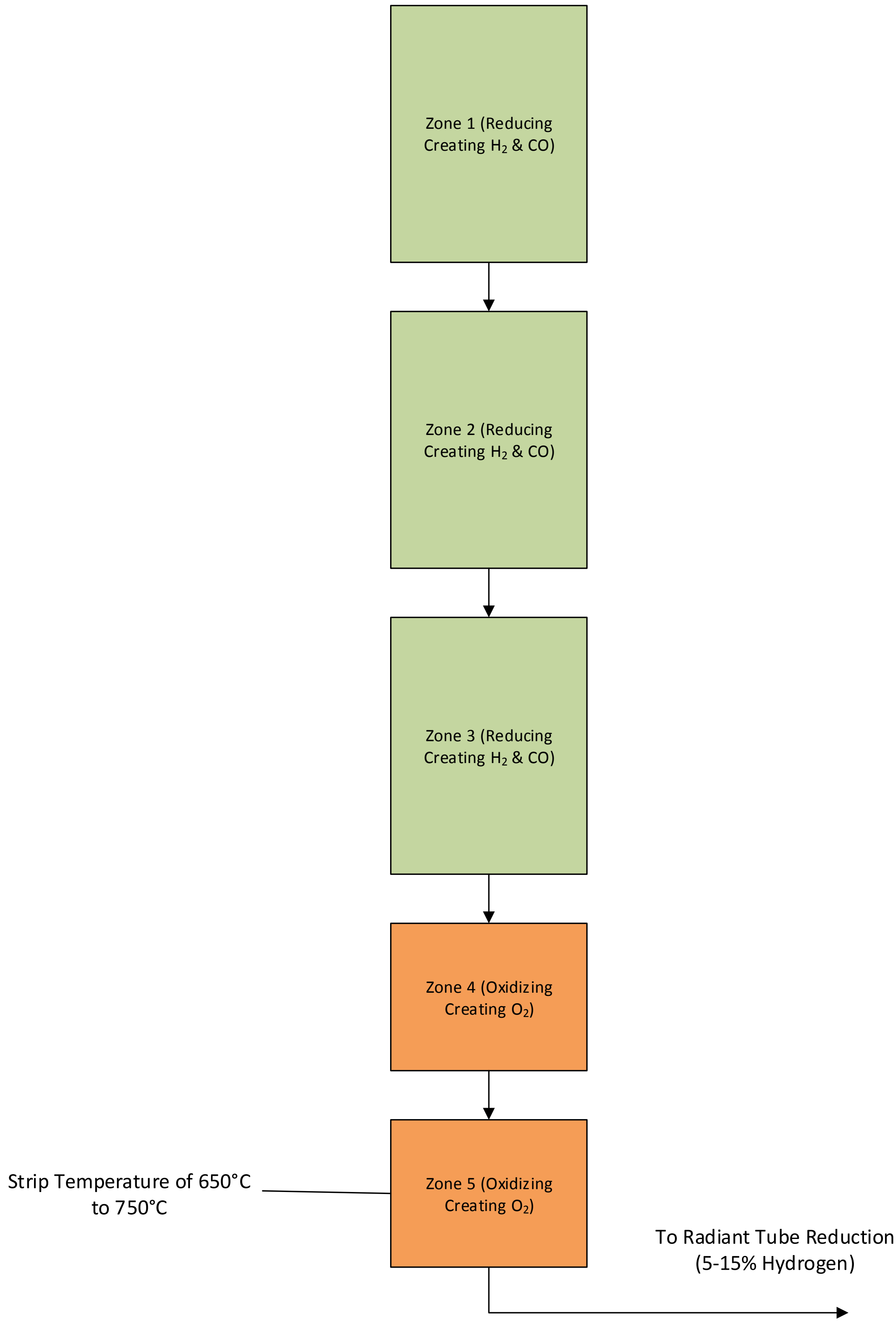

Figure 6 – Pictorial of "Common" Direct Fired Furnace Layout

As can be seen above, the first three zones operate in a reducing capacity ($\lambda<1.0$) to allow for cleaning and additional degreasing of the strip. The final zones 4 and 5 operating in an oxidizing capacity ($\lambda>1.0$) to implement the selective oxidation process. It is imperative that the selective oxidation occur in the temperature range of 650°C to 750°C.

Also, the oxidation must have a thickness of 200 to 300 nanometers (nm) of thickness. The oxidation of the AHSS and UHSS occurs at just over stoichiometric combustion, usually in the range of $1.01 \leq \lambda \leq 1.2$. If the oxidation layer is too thin, there will be zinc wetting issues as the non-wettable oxides will not be encased in an Iron Oxide (FeO) layer. If the oxidation layer is too thick, there will be non-complete reduction of oxides in the radiant tube and reduction furnaces. Also, from a physical furnace standpoint, the additional oxidation can induce roll pick up throughout the line and create strip to roll surface defects.

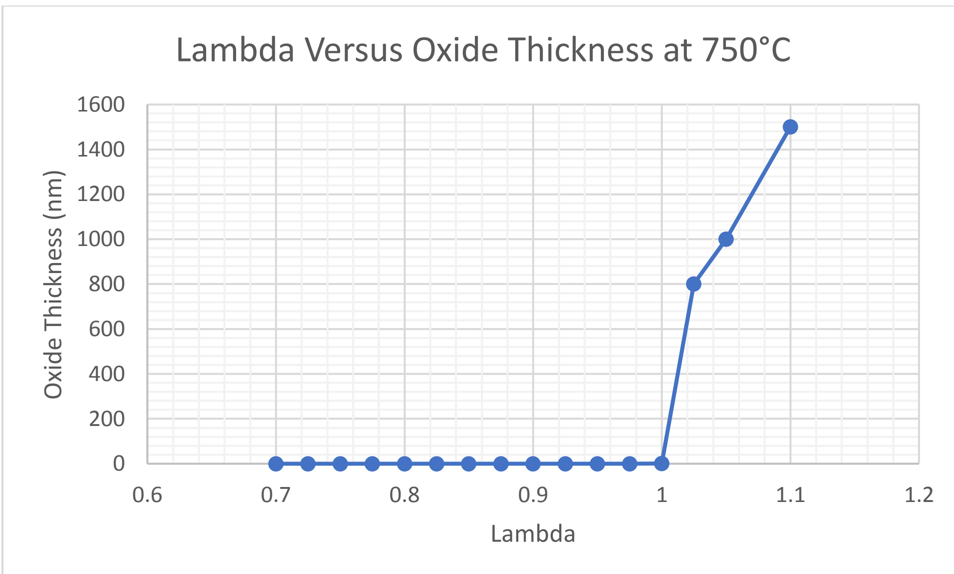

Figure 7 – ESTIMATED Comparison of Lambda to Oxide Thickness at 750°C

Arrangement of the burners is also important to consider. Just as in any other operation, there must be care given that the flame does not directly impinge on the steel strip. The burners best suited for this operation are high velocity, direct fired gas burners that operate above and below the pass line of the strip. The burners must be placed at the proper height to ensure that the strip remains in the isothermal zone of the burner pattern. This burner pattern can be determined utilizing CFD modeling as well as experience from combustion equipment suppliers with expertise in this type of equipment.

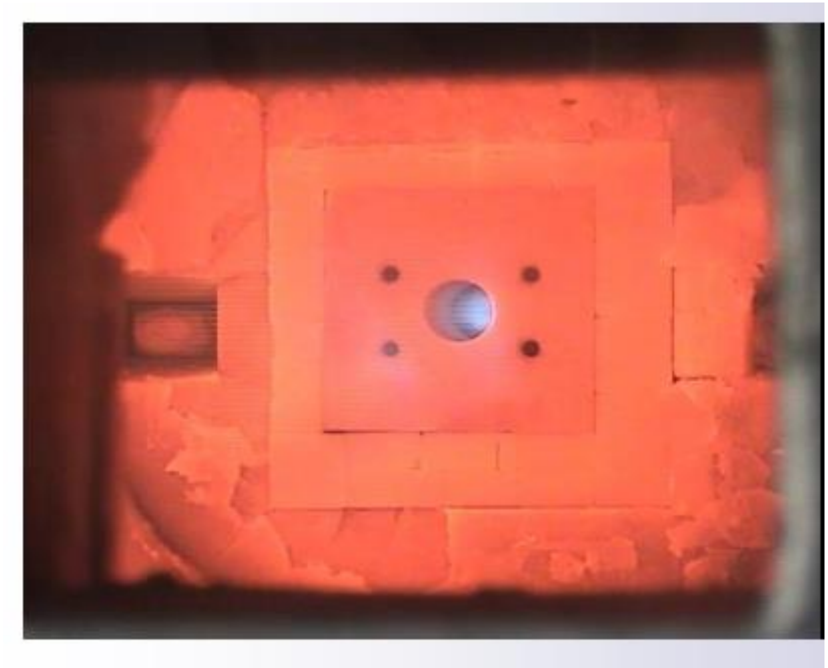

Figure 8 – Direct Fired Burner Operating Under Selective Oxidation Mode

Also, in today's operating conditions, all Hot Dip Galvanizing Lines must be able to be flexible. The description above of the selective oxidation process does not limit the galvanizing furnace to selective oxidation only. With the air to gas ratio control, the Direct Fired Furnace (DFF) or Non-Oxidizing Furnace (NOF) can also work in "normal" reducing mode. The final zones are controlled by its own control zones and can be made to sync with the remainder of the zones.

Operation Mode	**Selective Oxidation**	**Reducing Mode**
Lambda (λ)	$\lambda > 1.0$	$\lambda < 1.0$
Oxygen (O_2) Percentage	≤ 1.0	0
Hydrogen (H_2) Percentage	0	< 0.7
Carbon Monoxide (CO) Percentage	0	< 3.0

Figure 9 – Lambda Control and Associated Products of Combustion

CONCLUSIONS

With the need for today and the future automobiles to have greater fuel efficiencies and greater amounts of safety, the market for Advanced High Strength Steel (AHSS) and Ultra High Strength Steel (UHSS) will increase dramatically over the next decade. The chemistries of these steels require different ways to process for both physical properties as well as coatability on Hot Dip Galvanizing Lines. The use of selective oxidation in the Direct Fired Furnace (DFF) or Non-Oxidizing Furnace (NOF) can create the ideal properties, increase wettability in the zinc pot and minimize the capital expenditures in a new furnace. The furnace can be modified to process Advanced High Strength Steel (AHSS) and Ultra High Strength Steel (UHSS) as well as being able to continue to process other grades.

ACKNOWLEDGEMENTS

The authors would like to thank the laboratory personnel of Bloom Engineering Company, Inc. for confirmation of operating data as well as various other Bloom Engineering Company, Inc. personnel for assistance in creation of this work.