Experimental Determination of Continuous Cooling Transformation Diagrams in Advanced High Strength Steels under Continuous Galvanizing Conditions

Project Overview

IZA Program “ZCO-69 Galvanizing Thermal Cycle Effects on AHSS Properties”

NORTH AMERICAN GAP PROGRAM REVIEW MEETING
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Objective

• The aim of the present project is to determine continuous cooling transformation diagrams of advanced high strength steels subjected to thermal treatments simulating the industrial conditions of continuous, hot-dip, galvanizing lines.

• The effect of thermal history prior to final cooling on the distribution of resulting phases and mechanical properties of these materials will also be investigated.
Quenching Dilatometer LINSEIS-RITA

He Cooling

Heating and measuring chamber

Samples

Width or Diameter: 3-4 mm

Induction Heating

L=9-11 mm

Controller
Typical Heating and Cooling Curves

What can be done?
• What have we done?
Primary recrystallization kinetics and phase transformations in cold-rolled HSLA steels (C:0.06%, Mn:0.54%, Ti:0.01%, Nb:0.033%) under conditions that simulate an industrial continuous annealing process.

Case 1: Study of recrystallization on heating  
Case 2: Study of phase transformation

Plot \( T \) vs \( t \) and heat treatment cycles simulated by quenching dilatometry in the experimental HSLA steel
Microstructure of HSLA steel resulting from interrupted thermal treatments

Case 1

- As received “Cold-rolled condition”
  - F1 = 600°C
  - F1 = 610°C
  - F1 = 650°C
  - F1 = 730°C
  - F1 = 740°C
  - F1 = 750°C

- F1 = 700°C
- F1 = 720°C
- F1 = 730°C
- F1 = 740°C
- F1 = 750°C

Hardness (HV)

Temperature (°C)
Phase transformations

(left) Heating cycles and (right) dilation curves of HSLA steel as a function of temperature

Case 2
Background
For the same steel, two different industrial continuous annealing and galvanizing cycles were simulated. The resulting microstructures and hardness were compared and related to the processing parameters.
Effect of thermal history on the microstructure and hardness of the HSLA steel: left) Cycle 1 and right) Cycle 2

The grain size of sample subjected to cycle 1 is larger compared to that obtained from cycle 2. As a result, hardness of sample subjected to cycle 1 is lower than that subjected to cycle 2.
Continuous cooling transformation diagrams (CCT)

Hot-rolled heat treatable steel plates (%C:0.25, Mn:1.46. The results were compared with simulations by JMAtPro commercial software.

Theoretical estimation of austenite grain size: JMAt-Pro

Heat treatment cycle used to measure austenite grain size

G=22µm

G=29.6µm
Samples were cooled at rates ranging from 0.1 to 200°C/s.

Heat treating cycles of experimental hot-rolled heat treatable steel plates. Austenitizing temperature and time were 900°C and 10 min, respectively.
Experimental dilation curves obtained as a function of cooling rate (200-0.1°C/s) in the experimental steel.
CCT diagrams, microstructures and hardness resulting from heat treatments as a function of cooling rate.
Effects of several continuous annealing processing conditions on the microstructure and mechanical properties of AISI 1012 carbon steels.
Microstructures resulting from heat treating cycles carried out in the continuous annealing simulator
# Mechanical properties of heat-treated samples

<table>
<thead>
<tr>
<th>Condition</th>
<th>$\sigma_y$ (MPa)</th>
<th>UTS (MPa)</th>
<th>Ef (%)</th>
<th>Hardness (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-receive cold rolled steel</td>
<td>864</td>
<td>891</td>
<td>3</td>
<td>250</td>
</tr>
<tr>
<td>Cycle 1</td>
<td>340</td>
<td>394</td>
<td>33</td>
<td>135</td>
</tr>
<tr>
<td>Cycle 2</td>
<td>330</td>
<td>394</td>
<td>30</td>
<td>125</td>
</tr>
<tr>
<td>Cycle 3</td>
<td>321</td>
<td>392</td>
<td>32</td>
<td>125</td>
</tr>
<tr>
<td>Cycle 4</td>
<td>236</td>
<td>357</td>
<td>24</td>
<td>120</td>
</tr>
</tbody>
</table>

- Increased heating rate
- Increased holding time
- Increased $F_1$ and $F_2$
Justification

The demand of automobile industry for higher UTS strength steels has led to more complex alloy design. Nowadays, advanced high strength steels producers are interested in the generation of useful information regarding phase transformations of these steels under conditions that simulate the continuous, hot-dipped, galvanizing lines. This need represents the driving force of the present investigation.
Automotive steel strength/ductility ladder
Too many different steel types!

Low carbon and conventional high strength steels (HSSs)
- Low carbon steels (LC)
- Solid solution strengthened (SSS)
- Bake hardenable (BH)
- High strength low alloy (HSLA)

First generation advanced high strength steels (AHSSs)
- Dual phase (DP) – ferrite/martensite
- High hole expansion (HHE) – ferrite/bainite
- Stretch flangeable (SF)
- Transformation induced plasticity (TRIP)
- Complex phase (CP)
- Fully martensitic (MS)
- Boron heat treatable steels

Second generation advanced high strength steels
- Twinning induced plasticity (TWIP)
- Lightweight steels with induced plasticity (L-IP)
Typical thermal cycles for First Generation AHSS’s

All of them can be simulated in the Dilatometer!!!
Methodology
Stage 1

As-received advanced high strength steel AHSS

Literature review
- Available TTT and CCT diagrams for AHSS
- Thermal histories used industrially in continuous galvanizing lines for AHSS

JM AT-PRO simulations
- Estimation of austenite grain size as a function of temperature and time
- Evaluation of chemical composition and grain size on the behavior of CCT diagrams

Characterization of the as-received AHSS
- Chemical composition
  - Combustion method
  - Optical spectrometry
- Microstructure
  - Optical microscopy
  - Scanning electron microscopy
  - Electron backscattering diffraction and orientation imaging microscopy
- Hardness and uniaxial tension tests
Quenching dilatometry - Processing variables: T, t, dT/t

Determination of critical phase transitions from ΔL vs T, ΔL vs t curves

Microstructure - Optical microscopy
- Scanning electron microscopy
- Orientation imaging microscopy

Microhardness

Selected simulations in a continuous annealing simulator - Processing variables: T, t, dT/t

Microstructure
- Optical microscopy
- Scanning electron microscopy
- Orientation imaging microscopy

Uniaxial tension tests
- Ultimate tensile strength
- Yield strength
- Elongation to fracture

Experimental
Conclusions

• It is possible to simulate a large variety of heat treating schedules by quenching dilatometry, from simplest to most complex ones, with a precise control over heating and cooling rates (0.1-200°C/s), temperature (≤1100°C) and time. In addition, interrupted thermal treatments can be carried out at any stage and, therefore, the microstructural evolution can be followed through the cycle.
Conclusions

• Scanning electron microscopy and hardness can be used as a complement to quenching dilatometry. Besides, yield and tensile strength as well as elongation to fracture can be determined in samples thermally treated in the continuous annealing simulator.

• Finally, it would be possible to establish the CCT diagrams or the processing-microstructure-properties relation for any steel grade.
What do we need to achieve the objectives?

Two things are required to develop the proposed project:

• The heat treating cycles indicating the processing conditions that will be simulated.

• The steel samples that will be used for the thermal treating simulations.
Thank you !!!