Development of an Ultrasonic C-Scan Imaging Technique for Optimization of Electro Magnetic Stirrer to Improve Steel Billet Quality

Manish Raj
& Ramesh Kumar Ajmeria
Jindal Steel and Power Ltd., India

World Conference on NDT (WCNDT) 2012
Durban, South Africa
April 16, 2012
**Electro Magnetic Stirrer (EMS)**

In simple words, the purpose of EMS is to homogenize the steel melt in order to obtain a favourable solid structure after solidification.

**Benefits are:**

- Improvement in cast structure through increased volume of equiaxed grains,
- Reduced degree of macro-inclusions, especially in the central portion of cross sections,
- Improved surface quality, and
- Reduced shrinkage porosity.
**Relative locations of EMS (three types)**

- **Mould Stirrer (M-EMS)**
  - Active on:
    - Surface (entrapped slag)
    - Pinholes and blowholes
    - Sub-surface inclusions
    - Segregation and porosity
    - Equiaxed structure

- **Strand Stirrer (S-EMS)**
  - Active on:
    - Size of the equiaxed structure
    - Centre porosity, segregation

- **Final Stirrer (F-EMS)**
  - Active on:
    - Centre segregation
    - Centre porosity
**Ultrasonic C-scan technique**

**Principle:**
A very high frequency ultrasonic signal (up to 50 MHz) is transmitted to the sample by a (focused beam) transducer. The sample and the transducer are submerged in water that serves as the coupling medium. The initial signal is partially reflected back to the transducer at interfaces, defects, porosities and at strong differences in acoustic impedance in the sample and the rest of the signal, if not fully reflected continues through the sample.

**Evaluation:**
The peak amplitudes as well as the time-of-flight of each returning signal is stored in a computer data file and processed off-line to produce maps of the scanned area at a particular depth, showing the sound and the defective regions.
It is a two dimensional graphical presentation, in which the discontinuity echoes are displayed in a top view on the test surface. In the presentation, reflected pulses are shown as events.

The event marks represent the echo by different evaluations:

- echo exceeding a preset threshold within a gate, the drawn a mark (0/1 method).
- echo exceeding a preset threshold within a gate and the drawn color palette (or grayscale) is proportional to the amplitude of the signal.
Ultrasonic C-scanning presentation
Ultrasonic C-scanning equipment

1. Scanner

2. Pulser-Receiver

3. Data Acquisition System
## Chemical Composition and Other Details of Continuous Cast (CC) High Carbon (HC) Steel Billets

<table>
<thead>
<tr>
<th>Liquidus (°C)</th>
<th>Super Heat (°C)</th>
<th>Chemical Composition (Wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1475</td>
<td>48</td>
<td>C  0.79 - 0.82</td>
</tr>
</tbody>
</table>
EMS setting details

Existing EMS setting
EMS Current – 320 Amps
EMS Current – 4 Hz

EMS Setting during samples collection

<table>
<thead>
<tr>
<th>Heat no.</th>
<th>EMS Status</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>No EMS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Constant frequency 4 Hz and varying current, Amps</td>
<td>200, 250, 320, 350 &amp; 400</td>
</tr>
<tr>
<td></td>
<td>Constant current 320 Amps and varying frequency, Hz</td>
<td>4.0, 5.0 &amp; 6.0</td>
</tr>
</tbody>
</table>
Sample collection methodology

Each six inch long billet sample was further machine cut into two one inch samples for ultrasonic evaluation.
Equipment and evaluation parameters

Equipment used:
The samples were tested in a water tank using a 2 inches diameter 5 MHz ultrasonic focused beam probe. The C-scan images were obtained with the help of a computer controlled immersion ultrasonic C-scan system.

Ultrasonic Parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRF</td>
<td>100 Hz</td>
</tr>
<tr>
<td>Gain</td>
<td>40 dB</td>
</tr>
<tr>
<td>Energy</td>
<td>50 uJ</td>
</tr>
<tr>
<td>Damping</td>
<td>100 ohms</td>
</tr>
<tr>
<td>Voltage output (amplitude)</td>
<td>+ 3 to - 3 and</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.2 mm x 0.2 mm</td>
</tr>
</tbody>
</table>
Macro-structure of CC billet sample

Schematic diagram

Image revealed by Ultrasonic C-Scan

A – Chill zone
B – Anisotropic columnar grains
C – Equiaxed zone
D – Central void

Copyright © 2010 Jindal Steel & Power Ltd.
Optimisation of EMS frequency
Ultrasonic C-scan images of CC billet sample (Strand 1, EMS current 320 A)

- Chilled Zone (A)
- Columnar grains (B)
- Central void (D)
- Equiaxed grains (C)

Frequency 4 Hz
Frequency 5 Hz
Frequency 6 Hz
Ultrasonic C-scan images of CC billet sample (Strand 2, EMS current 320 A)
Effect of EMS frequencies (Strand 1, EMS current 320 A)

% equiaxed zone

Equi axed zone, %

<table>
<thead>
<tr>
<th>Frequencies</th>
<th>4Hz</th>
<th>5Hz</th>
<th>6Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>% area of central void</td>
<td>55%</td>
<td>50%</td>
<td>45%</td>
</tr>
<tr>
<td>Area of central void</td>
<td>6%</td>
<td>4%</td>
<td>2%</td>
</tr>
</tbody>
</table>

% area of central void

4Hz 5Hz 6Hz

320A 320A 320A

Copyright © 2010 Jindal Steel & Power Ltd.
Effect of EMS frequencies
(Strand 2, EMS current 320 A)

% equiaxed zone

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Hz</td>
<td>320</td>
</tr>
<tr>
<td>5 Hz</td>
<td>320</td>
</tr>
<tr>
<td>6 Hz</td>
<td>320</td>
</tr>
</tbody>
</table>

% area of central void

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Hz</td>
<td>320</td>
</tr>
<tr>
<td>5 Hz</td>
<td>320</td>
</tr>
<tr>
<td>6 Hz</td>
<td>320</td>
</tr>
</tbody>
</table>
Observations

It is found, from the above figures:

• The % equiaxed zone is quite significant and consistent at EMS frequency 4 Hz and it do not increases significantly with the increase in EMS frequency.

• The % area of central void in the billet samples, with respect to the total area of billet section, also does not change considerably with increase in EMS frequency.

• Therefore, EMS frequency was not raised further and considered optimum as 4 Hz.
Optimisation of EMS current
Ultrasonic C-scan images of CC billet sample (Strand 1, EMS frequency 4 Hz)
Ultrasonic C-scan images of CC billet sample (Strand 2, EMS frequency 4 Hz)
Effect of EMS current (Strand 1, EMS frequency 4 Hz)

- **Equi-axed zone, %**
  - 4Hz
  - 300A: 50%
  - 320A: 55%
  - 350A: 50%

- **Area of central void**
  - 4Hz
  - 300A: 0%
  - 320A: 2%
  - 350A: 6%
**Effect of EMS current**
*(Strand 4, EMS frequency 4 Hz)*

![Graph showing the effect of EMS current on equiaxed zone and area of central void.](chart)

- **Equi axed zone, %**
  - 4Hz
  - 300A: 45%
  - 320A: 50%
  - 350A: 55%

- **Area of central void**
  - 4Hz
  - 300A: 0%
  - 320A: 2%
  - 350A: 6%

Copyright © 2010 Jindal Steel & Power Ltd.
**Observations**

It is found, from the above figures:

- the % of equiaxed zone is significant as well as consistent at EMS current 320 A (existing practice) and it does not increases significantly with the further increase in EMS current.

- The % area of central void in the billet samples, with respect to the total area of billet section, also does not change considerably with further increase in EMS current.

- Hence, EMS current was not increased further and considered optimum as 320 A.
Conclusions
• The change in EMS frequency from 4 Hz to 6 Hz, with varying EMS current 300 A to 350 A did not resulted in further improvement in billet quality.

• The current setting of EMS i.e. 4 Hz frequency and 320 A current is the optimum setting to get good quality of CC billets.

• The qualitative as well as quantitative evaluation of central void and columnar/equi-axed zone in the continuously cast billets was possible using ultrasonic immersion C-Scan imaging technique.
Thank You