Online Material Characterisation at Strip Production

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### Measurable quantities by used methods

<table>
<thead>
<tr>
<th><strong>Electromagnetic</strong></th>
<th><strong>Ultrasonic</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct signals</strong></td>
<td>Speed of sound, damping, Reflections from phase borders</td>
</tr>
<tr>
<td>Hysteresis features</td>
<td></td>
</tr>
<tr>
<td>Eddy current features</td>
<td></td>
</tr>
<tr>
<td><strong>Physical properties</strong></td>
<td></td>
</tr>
<tr>
<td>Remanence, coercitivity, magnetic loss, differential permeability, impedance</td>
<td>Elasticity, Scattering, absorption, Change in refractive index</td>
</tr>
<tr>
<td><strong>Material properties</strong></td>
<td></td>
</tr>
<tr>
<td>Phase mixture, grain size, dislocation density, precipitation density, Phase composition ferrite / austenite</td>
<td>Elastic properties, Hardness, Phase changes, Yield strength, Microstructure, Grain size, Phase changes, Defect detection</td>
</tr>
</tbody>
</table>
### Project Structure

<table>
<thead>
<tr>
<th></th>
<th>Ultrasonic</th>
<th>Electromagnetic</th>
<th>Destructive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laser Ultrasonic</strong></td>
<td>IMPOC</td>
<td>Hacom</td>
<td>Multi Frequency Impedance Analyser (MFIA)</td>
</tr>
<tr>
<td><strong>Online</strong></td>
<td>KIMAB, SZMF</td>
<td>TKS, FQZ, AMEH</td>
<td>SZMF</td>
</tr>
<tr>
<td><strong>Samples</strong></td>
<td>KIMAB, SZMF</td>
<td>TKS, FQZ, AMEH</td>
<td>SZMF, CEIT</td>
</tr>
<tr>
<td><strong>Simulation</strong></td>
<td></td>
<td></td>
<td>TATA</td>
</tr>
<tr>
<td><strong>Data Mining</strong></td>
<td>BFI</td>
<td>SZMF, CEIT</td>
<td>TATA</td>
</tr>
<tr>
<td><strong>Disturbance</strong></td>
<td>BFI</td>
<td></td>
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</tr>
</tbody>
</table>
OBJECTIVES

- Development of advanced online measurement techniques characterising the structural parameters of the material to predict online the strip quality.
- Development of measurement techniques and systems for production lines with unfavourable conditions.
- Online measurement data from the actual produced material for the adjustment of process models to predict material quality with high resolution on the strip.
- Evaluation algorithm relating the measured quantities to mechanical technological values.
- Development of advanced methods like classification, neural networks or decision trees to derive online interesting material quantities for quality control of production.
Content
1  Basic Specifications
2  Application of Electromagnetic Methods
3  Application of Ultrasonic Methods
4  Assessment of the Results and Discussion
1. Basic Specifications, Methods

Electromagnetic online Methods used in the project

**IMPOC** (available system)
Magnetic pulse, gradient of remanence

**HACOM** (available system)
Sinusoidal magnetisation, harmonic analysis
1 Basic Specifications, Methods

Electromagnetic laboratory Methods used in the project

Single Sheet tester
(available system)

H-Pulses kA/m

Multi Pulse Impoc (Development)
Magnetic pulse cycles of different amplitude, gradient of remanence
1 Basic Specifications, Methods

Electromagnetic online methods developed in the project

**MFIA**, Multi frequency impedance analyser
change of flux rate (eddy current)
1 Basic Specifications, Methods

Ultrasonic methods used in the project

**Laser Ultrasound**

Excitation by Laser-pulse
Detection by Interferometer

Ultrasound of different wave modes
2 Application of Electromagnetic Methods, High Speed Im poc

High speed IMPOC installation at the CAL in Dortmund

Shape of magnetisation coils, amplitude and frequency of pulses changed,

Results: No difference in shape of signals, good correlation to mechanical values for IF and MA steel

High speed IMPOC installation at the CGL2 in Eisenhüttenstadt

Shape of magnetisation coils, amplitude and frequency of pulses changed,

Results: A distance reduction (66 mm to 50 mm) increases the signal amplitude by app. 10%
The change of IMPOC to HighSpeed IMPOC decreases the signal amplitude by 5 - 7%
An adaptation of the system at a production line and/or the change of system type is possible

Direct comparison with two systems in the same line with different lift off
Ferrite fraction governs magnetic permeability:
2 Application of Electromagnetic Methods, MFIA

MFIA output for a low C/Mn steel grade

Developments:
- MFIA sensor + Instrumentation electronics
- Software and firmware to control the MFIA-sensor, to evaluate the results, to present basic measurements
- Results from sensitivity studies on samples (in lab)
- An industrial housing to protect the sensor on the mill in a very hostile environment
- Initial result from a production HSM
speed influence of H360LA steel grade

\[ y = -1.2887x + 10607 \]

\[ R^2 = 0.8576 \]
The signal change with speed depends on Strip Thickness and Material.
2 Application of Electromagnetic Methods, Modelling

Prediction of coarse grain from HACOM values at strip material

HACOM Signals

oven temperatures

<- Strip length ->

Grain Structure

<table>
<thead>
<tr>
<th>Coarse grain (micro graph)</th>
<th>Position-information [m]</th>
<th>Prediction (&quot;true&quot;)</th>
<th>Prediction (&quot;false&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>true</td>
<td>0.95</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>false</td>
<td>0.18</td>
<td>0.82</td>
<td></td>
</tr>
</tbody>
</table>
Multi Pulse IMPOC measurements, effects of skin pass treatment, different steel grades
Magnetic properties can be directly related to mechanical properties.

**Step 1 and 2**

**Step 3 and 4**

**UD1/UD2**
Banded microstructures

**UD3/UD4**
Equiaxed microstructures

![Graphs showing magnetic properties and mechanical properties](chart)

\[ y = 4.2709x - 531.81 \]

\[ R^2 = 0.9992 \]
Correlations between coercive field and mechanical yield strength for all the studied samples.
No Correlations between magnetic hysteresis losses and remanent field

H_c, B_r, different information about microstructure

H_c significantly affected by carbon content, micro structural phase, grain size, dislocation density,

B_r significantly affected by residual stresses, texture less by grain size, dislocation density

H_c, M_L equivalent information about microstructure
3 Application of Ultrasonic Methods, Mechanical Models

**LUS Ultrasound propagation**

- a) normal to surface, predefined thickness.
- b) different angles, velocity from comparison of different echo arrival times.
- c) A combination of a) and b)

**LUS elastic constants**

\[
E = \frac{\sigma_{ii}}{\varepsilon_{ii}} = \frac{V_S(3V_P - 4V_S)}{(V_P - V_S)}
\]

Young’s modulus

\[
\nu = -\frac{\varepsilon_{ij}}{\varepsilon_{jj}} = \frac{(V_P - 2V_S)}{2(V_P - V_S)}
\]

Poisson’s ratio

**LUS-Parameter**

- normalised attenuation = \[\int_{f=\text{high \_ frequencies}} \frac{\text{Spectrum}(f)}{\int_{f=\text{low \_ frequencies}} \text{Spectrum}(f)}\]

**Attenuation**

\[
U(f) = U_0(f)e^{-\alpha f^v}
\]

- d: grain diameter
- v: exponent 2..4
- \(\alpha = K \times d^{v-1} \times f^v\)
  - 4 in case of Rayleigh scattering
3 Application of Ultrasonic Methods, Online Measurements

Setup of LUS measurements at the annealing simulator. The specimen is not visible due to the heat shielding.

Industrial installation of laser ultrasound at SSAB. Fibre coupled optical head in the format line.

US-velocity over coil length
3 Application of Ultrasonic Methods, Laboratory Samples, Characterisation

LUS Measurement at hot strip samples  heat treatment 950°C  1: 0 min, 2: 1min, 3: 10min, 4: 60min, 5: 240min

**Sound Velocity**

- **51CrV4**

<table>
<thead>
<tr>
<th>Annealing time /min</th>
<th>Sound velocity m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6000</td>
</tr>
<tr>
<td>1</td>
<td>6000</td>
</tr>
<tr>
<td>2</td>
<td>6000</td>
</tr>
<tr>
<td>3</td>
<td>6000</td>
</tr>
<tr>
<td>4</td>
<td>6000</td>
</tr>
<tr>
<td>5</td>
<td>6000</td>
</tr>
</tbody>
</table>

**LUS-Parameter**

- **DD13**

<table>
<thead>
<tr>
<th>Annealing time/ min</th>
<th>LUS-Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
3 Application of Ultrasonic Methods, Laboratory Samples, Characterisation

LUS Spectra at hot strip samples, a-h increasing Martensite content

- HSLA1
- DP2
- Mart.2
- HSLA2
- DP3
- Mart.3
- DP1
- Mart.1
## Online methods examined

<table>
<thead>
<tr>
<th>Online System</th>
<th>Type of line</th>
<th>Position</th>
<th>Structural Parameters</th>
<th>Application</th>
<th>Main disturbing influence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IMPOC</strong> EM, gradient of remanence</td>
<td>Continuous lines, HDG, CAL, PL, low/high speed</td>
<td>Treatment part (little speed changes)</td>
<td>grain size, dislocations</td>
<td>Homogeneity, yield / tensile strength</td>
<td>strip speed, tension compensation models available</td>
</tr>
<tr>
<td><strong>MFIA</strong> EM, impedance</td>
<td>Hot strip, annealing</td>
<td>Roll out table, oven sections</td>
<td>Changes in impedance</td>
<td>Determination of ferritic phase fraction</td>
<td>Curie point, lift off</td>
</tr>
<tr>
<td><strong>LUS</strong> Ultrasound speed and frequency content</td>
<td>Slabs, Hot strip, Pickling line, Annealing line,</td>
<td>After finishing stands, Oven sections</td>
<td>Elastic constants, grain size, attenuation (phase dependent)</td>
<td>Homogeneity, grain size in hot sections, (phase fraction)</td>
<td>High attenuation above 1170K, laser instabilities, scale, air turbulences, steam</td>
</tr>
</tbody>
</table>
4 Discussion of the results

- Magnetic losses, coercive field, permeability are main features for microstructure characterisation, textural information more from remanence.

- All examined EM methods related to features of the hysteresis loop. Single sheet tester base method to determine relations of magnetic to micro structural parameters.

- MFIA (permeability) shows development of the phase fraction, IMPOC and HACOM (magnetic losses, coercive field) are sensitive for features of microstructure and mechanical parameters.

- Sound speed, attenuation and US-spectra give access to micro structure. Laser-exited ultrasound applicable for temperature dependent measurements. Characteristic features in the spectra change with micro structure.

- Determination of material quantities at elevated and high temperatures. Calibration to material states is necessary.
Thank you for your attention

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