Optimisation of Neural Network for Charpy Toughness of Steel Welds

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Modelling of output

Bias in Models

Interpass temperature effect
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  Discussion

Conclusions
Introduction

Neural network

Empirical equation $\rightarrow$ unphysical values

Possible

Charpy toughness (Impact toughness)

Measured energy absorbed by a standard sample during fracture

Never be negative!
Example of non-physical prediction
Modelling of output (Yescas et al. 2001)

Volume fraction from Avrami theory

\[ \xi = 1 - \exp(-kt^n) \]

\( \xi \): volume fraction \hspace{1cm} k, n: constants \hspace{1cm} t: time

\[ \ln[- \ln(1 - \xi)] \propto n \ln t \]

\[ 0 \leq \xi \leq 1 \]

Double logarithmic function for output
Modelling of output (this work)

New output form

\[ y' = - \ln \left( - \ln \left( \frac{y - y_{\text{min}}}{y_{\text{max}} - y_{\text{min}}} \right) \right) \]

\[ y_{\text{min}} = 0 \text{ J} \quad \text{the least physical value of Charpy toughness} \]

\[ y_{\text{max}} = ? \quad \text{larger than the maximum value in database} \]

\[ y_{\text{max}} = 357 \text{ J or 3570 J} \]
Bias in Models

\begin{align*}
y_{\text{min}} &= 0 \text{ J} \\
y_{\text{max}} &= 357 \text{ J}
\end{align*}
Bias in Models

\[ y_{\text{min}} = 0 \text{ J} \quad y_{\text{max}} = 3570 \text{ J} \]
Bias in Models

The selection of $y_{\text{max}}$ $\rightarrow$ Bias

Unjustified!

Alternative way $y' = \ln y$

$\rightarrow$ Infinite value of $y_{\text{max}}$

Just use raw toughness value!
Interpass temperature

In multi-run welding, the temperature maintained immediately before depositing more metal.
Interpass temperature

Higher interpass temperature \( \rightarrow \) lower cooling rate
Results (0.5Mn)

Predicted impact toughness

Ni / wt%
Results (2Mn)

Predicted impact toughness / J

High
Intermediate

Ni / wt%
Discussion (CCT and cooling curve diagram)

- Low Ni and low Mn
- Low Ni and high Mn
- High Ni and low Mn
- High Ni and high Mn
- Increasing interpass temperature
Conclusions

Using logarithmic representation of Charpy toughness introduced unjustified bias.

Interpass temperature cause different effect to Charpy toughness with respect to Ni and Mn.
Thank you
### Input data (modelling bias)

All elements are in wt% unless otherwise specified.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.034</td>
<td>0.27</td>
<td>2.14</td>
<td>0.008</td>
<td>0.01</td>
<td>7.3</td>
<td>0.5</td>
<td>0.62</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>V</th>
<th>Cu</th>
<th>Co</th>
<th>W</th>
<th>O / ppmw</th>
<th>Ti / ppmw</th>
<th>N / ppmw</th>
<th>B / ppmw</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.011</td>
<td>0.03</td>
<td>0.009</td>
<td>0.005</td>
<td>330</td>
<td>80</td>
<td>120</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Nb / ppmw</th>
<th>HI / kJ mm⁻¹</th>
<th>IT / °C</th>
<th>PWHTT / °C</th>
<th>PWHTt / h</th>
<th>DₑFe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>1</td>
<td>250</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

HI: Heat input  
IT: Interpass temperature  
PWHTT: Post-weld heat treatment temperature  
PWHTt: Post-weld heat treatment time  
DₑFe: A variable considering iron diffusion during post-weld heat treatment
## Input data (Ni-IT prediction)

All elements are in wt% unless otherwise specified.

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.025</td>
<td>0.37</td>
<td>0.65 / 2</td>
<td>0.006</td>
<td>0.013</td>
<td>6.6</td>
<td>0.21</td>
<td>0.4</td>
</tr>
<tr>
<td>V</td>
<td>0.011</td>
<td>0.03</td>
<td>0.009</td>
<td>0.005</td>
<td>380</td>
<td>80</td>
<td>180</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>Nb / ppmw</th>
<th>HI / kJ mm^{-1}</th>
<th>IT / °C</th>
<th>PWHTT / °C</th>
<th>PWHTt / h</th>
<th>D_{Fe}</th>
<th>TT / °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>1</td>
<td>250</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>-60</td>
</tr>
</tbody>
</table>
Calculation of $t_{8/5}$ (Svensson et al., 1986)

$t_{8/5}$: cooling time from 800 °C to 500 °C

Higher $t_{8/5} \rightarrow$ lower cooling rate

Under the heat input of 1.53 kJ

<table>
<thead>
<tr>
<th>Interpass temperature (°C)</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{8/5}$ (s)</td>
<td>11.7</td>
<td>16.6</td>
<td>26.3</td>
<td>53.1</td>
</tr>
</tbody>
</table>
High transformation temperature \( \rightarrow \) coarser microstructure (Lord, 1999)
Interpass temperature effect
Evidence (Lord, 1999)

CHV (99 °C IT) < CHV (38 °C IT)
Results (0.5Mn)

Predicted impact toughness

Uncertainty / J
Results (2Mn)

Predicted impact toughness / J

Uncertainty / J

Ni / wt%
Discussion (Ni-Mn prediction)

- High Ni, low Mn
- High Ni, low Mn
Double logarithms

Yescas’s work

This work