CHARACTERIZATION OF ANISOTROPIC WELD STRUCTURES FOR NUCLEAR INDUSTRY

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INDEX

1. INTRODUCTION

2. UT BEAM BEHAVIOUR IN ANISOTROPIC MATERIALS

3. GRAIN ORIENTATION IN WELDS

4. NUCLEAR-WELD INSPECTION
   4.1 Definition of the transducers
   4.2 CIVA analysis
   4.3 Experimental results
   4.4 Discussion

5. CONCLUSIONS
INDEX

1. INTRODUCTION

2. UT BEAM BEHAVIOUR IN ANISOTROPIC MATERIALS

3. GRAIN ORIENTATION IN WELDS

4. NUCLEAR-WELD INSPECTION
   4.1 Definition of the transducers
   4.2 CIVA analysis
   4.3 Experimental results
   4.4 Discussion

5. CONCLUSIONS
• IK4-IDEKO is a private Basque research centre (northern Spain) specialized in Manufacturing and Production technologies.

Europe R&D projects

>20 years

>50 projects

40% Co-ordinator
Located in Elgoibar (Basque Country – Spain), it has 8 RESEARCH LINES which offer comprehensive solutions in manufacturing and industrial production technologies and provide the necessary balance to transfer research results to the company based on the generation of knowledge.

Associated to:

**DANOBATGROUP**
- First Spanish Machine-Tool builder group

**MONDRAGON Corp.**
- One of the largest industrial corporation in Spain

**IK4 Research Alliance**
- 9 R&D centers and >1400 researchers (320 PhD)
Inconel weld from the residual hot nozzle of AP1000 nuclear generators (Westinghouse)

**Complexity**
- Different interfaces
- Anisotropic grains
- Grain size
- Increased of the thickness

**Strict safety requirements**
- To ensure the quality and correctness of the weld.

- Requirement of new technologies for weld inspection in Nuclear Industry
Simulations

- The **CIVA software** is an expertise platform dedicated to non-destructive testing
- UT simulation tools include beam propagation and its interaction with flaws or specimens

Experimental results

- Results with conventional transducers have been obtained using the **OmniScan MX [16:128]** ultrasonic equipment
- Results with phased array transducers have been obtained using the **Focus LT [64:128]** ultrasonic equipment and **TomoView** software
• Material anisotropy has been considered Orthorombic

\[
\begin{bmatrix}
C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\
C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\
C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\
0 & 0 & 0 & C_{44} & 0 & 0 \\
0 & 0 & 0 & 0 & C_{55} & 0 \\
0 & 0 & 0 & 0 & 0 & C_{66}
\end{bmatrix}
\]

• The slowness curves have been obtained using Christoffel equation

\[
\rho V^2 \delta_{i\kappa} - C_{ijkl} n_j n_k = 0
\]

• The slowness curves of longitudinal waves are the following ones.
Beam behaviour at the interfaces is based on ‘Fermat principle of stationary time’

**Incidence angle: 0°**

<table>
<thead>
<tr>
<th>Grain orientation: 0°</th>
<th>Grain orientation: 30°</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Graph 1st MEDIA" /></td>
<td><img src="image2" alt="Graph 1st MEDIA" /></td>
</tr>
<tr>
<td><img src="image3" alt="Graph 2nd MEDIA" /></td>
<td><img src="image4" alt="Graph 2nd MEDIA" /></td>
</tr>
</tbody>
</table>

Results using slowness curves

Results obtained from CIVA
Beam behaviour at the interfaces is based on ‘Fermat principle of stationary time’

**Incidence angle: 5°**

Results using slowness curves

Results obtained from CIVA
The beam can suffer from division

Incident angle: 0°
Grain orientation: 30°

Incident angle: 0°
Grain orientation: 0°
1. INTRODUCTION

2. UT BEAM BEHAVIOUR IN ANISOTROPIC MATERIALS

3. GRAIN ORIENTATION IN WELDS

4. NUCLEAR-WELD INSPECTION
   4.1 Definition of the transducers
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   4.3 Experimental results
   4.4 Discussion

5. CONCLUSIONS
Three theoretical models have been used in this analysis.

- **Lanrenberg**
  \[
  \tan(\theta_1) = \frac{T_1(D_1 + z \tan(\alpha_1))}{y^n} \quad \text{for } y > 0
  \]

- **Ogilvy**
  \[
  \tan(\theta_2) = \frac{T_2/D_2 + z \tan(\alpha_2)}{y^n} \quad \text{for } y < 0
  \]

- **Schmitz**
  \[
  N_x = x^{0.1}
  \]
  \[
  N_y = 0
  \]
  \[
  N_z = -0.1z
  \]
1. INTRODUCTION

2. UT BEAM BEHAVIOUR IN ANISOTROPIC MATERIALS

3. GRAIN ORIENTATION IN WELDS

4. NUCLEAR-WELD INSPECTION
   4.1 Definition of the transducers
   4.2 CIVA analysis
   4.3 Experimental results
   4.4 Discussion

5. CONCLUSIONS
Weld material

Reflectors on the mock-up

Definition of the weld
Definition of the transducers

• Conventional transducers:

<table>
<thead>
<tr>
<th>CONVENTIONAL TRANSDUCERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>2.25 MHz</td>
</tr>
<tr>
<td>1 MHz</td>
</tr>
</tbody>
</table>

• Phased array transducers:

<table>
<thead>
<tr>
<th>LINEAR PHASED ARRAY</th>
<th>DUAL MATRIX ARRAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Element conf.</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
</tr>
<tr>
<td>5 MHz</td>
<td>64x1</td>
</tr>
</tbody>
</table>
• Definition of the grain orientation in the weld

- Lanrenberg
- Ogilvy: 0.5
- Ogilvy: 1
- Schmitz
Results with conventional transducers

**1st TRANSDUCER (f=2.25 MHz; φ= 16 mm)**

- Lanrenberg
- Ogilvy: 0.5
- Ogilvy: 1
- Schmitz
Results with conventional transducers

2\textsuperscript{nd} TRANSDUCER ($f=1$ MHz; $\phi=32$ mm)

- Lanrenberg
- Ogilvy: 0.5
- Ogilvy: 1
- Schmitz
Results with phased-array transducers

Sectorial scanning: 50° - 60°

LINEAR PHASED ARRAY

Lanrenberg

Ogilvy: 0.5

Ogilvy: 1

Schmitz
- Results with phased-array transducers

Sectorial scanning: 40° - 70°

DUAL MATRIX ARRAY

Lanrenberg

Ogilvy: 0.5

Ogilvy: 1

Schmitz
• Results with conventional transducers

1\textsuperscript{st} TRANSDUCER (f=2.25 MHz; ø= 16 mm)

2\textsuperscript{nd} TRANSDUCER (f=1 MHz; ø= 32 mm)
• Results with phased-array transducers

**LINEAR PHASED ARRAY**

Sectorial scanning: 50° - 60°

**DUAL MATRIX ARRAY**

Sectorial scanning: 40° - 70°
• Results with conventional transducers

1\textsuperscript{st}: f=2.25 MHz; ø= 16 mm

2\textsuperscript{nd}: f=1 MHz; ø= 32 mm

Early answer

Lanrenberg

Ogilvy: 0.5

Ogilvy: 1

Schmitz
• Results with conventional transducers

1\textsuperscript{st}: f=2.25 MHz; \(\varnothing = 16\) mm

2\textsuperscript{nd}: f=1 MHz; \(\varnothing = 32\) mm

---

\[\times\] Lanrenberg

\checkmark\ Early answer

Ogilvy: 0.5

---

Ogilvy: 1

Schmitz
• Results with conventional transducers

1\textsuperscript{st}: f=2.25 MHz; Ø = 16 mm

2\textsuperscript{nd}: f=1 MHz; Ø = 32 mm

![Images of ultrasound scans with annotations]

- **Lanrenberg**
  - Early answer

- **Ogilvy: 0.5**

- **Ogilvy: 1**

- **Schmitz**
Discussion

- Results with conventional transducers

1\textsuperscript{st}: f=2.25 MHz; \( \varnothing = 16 \text{ mm} \)

2\textsuperscript{nd}: f=1 MHz; \( \varnothing = 32 \text{ mm} \)

- Early answer: Lanrenberg
- Incorrect position: Schmitz
- Ogilvy: 0.5
- Ogilvy: 1
• Results with phased array transducers:

LINEAR PHASED ARRAY

DUAL MATRIX ARRAY

Lanrenberg

Ogilvy: 0.5

Ogilvy: 1

Schmitz
• Results with phased array transducers:

**LINEAR PHASED ARRAY**

**DUAL MATRIX ARRAY**

- Lanrenberg
- Ogilvy: 0.5
- Ogilvy: 1
- Schmitz
Results with phased array transducers:
Discussion

- Results with phased array transducers:

**LINEAR PHASED ARRAY**

**DUAL MATRIX ARRAY**

- Lanrenberg
- Ogilvy: 0.5
- Ogilvy: 1
- Schmitz
1. INTRODUCTION

2. UT BEAM BEHAVIOUR IN ANISOTROPIC MATERIALS

3. GRAINORIENTATION IN WELDS

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   4.3 Experimental results
   4.4 Discussion

5. CONCLUSIONS
• The results obtained show that the propagation of the beam is not a straight line.
  ➢ Grain anisotropy
  ➢ Grain orientation
  ➢ Grain size

• The study of the propagation of the beam helps to understand the results obtained and to optimize the transducer configuration.

• Weld models have been determined and simulations have been carried out using CIVA.

• These results have been validated in the laboratory, concluding Ogilvy model as the best approximation, specifically, Ogilvy with $\eta=0.5$. 
¡MUCHAS GRACIAS!

ESKERRIK ASKO!

THANK YOU!