Poisson's Ratio Scanning Using Immersion Ultrasonic Testing

Jin-Ha Park  Seo-Young Oh  Young H. Kim  Seung S. Lee
Poisson’s Ratio

• Poisson’s ratio ($\mu$) = - transverse strain/axial strain

• Large $\mu$ ~ softer material

• However, rarely used because:
  – Narrow range of value
  – Long. trans. wave velocities must be measured

• Dimensionless parameter
- Poisson’s ratio decreases with increase in ultrasonic velocities.
- Micro-structural variation or temperature has an effect on ultrasonic velocities.

(A. Kumar et al., Acta Materialia, 2003)
Poisson’s ratio and microstructure

- Negative poisson’s ratio.
How to measure Poisson’s ratio

- Destructive testing
  - Tensile test
- Nondestructive testing
  - Contact method
  - Noncontact method
Dry couple

- Nondestructive contact method
- Dry coupling
- Measured wave velocities using longitudinal and transverse transducers.

(Don J. Roth et al, NASA Technical Paper, 1993)
PVDF film

- PVDF (polyvinylidene fluoride) – piezoelectric
- NDT
- High frequency: thickness mode vib. (long.)
- Low frequency: radial mode vib. (trans.)

Fig. 2. PVDF transducer oscillation modes (a) transversal, (b) longitudinal.

Fig. 4. Signals obtained from one of the nylon test cylinder at different frequencies. The two top graphs correspond to shear mode of the emitter transducer and the two bottom graphs to the longitudinal mode.
• Normal beam contact transducer.
• Observation of mode converted transverse signals.

Fig. 6. Measured pulse-echo signal for a steel plate with a thickness of 12.7 mm.

Fig. 7. Measured pulse-echo signal for an aluminum plate with a thickness of 12.7 mm.

(Kim et al., J Korean Phys Soc, 2003)
Mode conversion of normal beam 2

- Good agreement with theoretical prediction.

Fig. 8. Comparison of experimental and calculated pulse-echo signals for a steel plate with a thickness of 12.7 mm.

Wave speeds were measured using immersion UT.

Table 1: Measured speeds of longitudinal and transverse waves for various specimens

<table>
<thead>
<tr>
<th>Material</th>
<th>Reference [5]</th>
<th>Contact method</th>
<th>Immersion method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$c_p$(m/s)</td>
<td>$c_s$(m/s)</td>
<td>$c_p$(m/s)</td>
</tr>
<tr>
<td>Silicon Nitride</td>
<td>11200</td>
<td>7000</td>
<td>13400</td>
</tr>
<tr>
<td>Aluminum</td>
<td>6374</td>
<td>3111</td>
<td>6410</td>
</tr>
<tr>
<td>Steel</td>
<td>5874</td>
<td>3179</td>
<td>6010</td>
</tr>
<tr>
<td>Copper</td>
<td>4759</td>
<td>2260</td>
<td>4680</td>
</tr>
<tr>
<td>Brass</td>
<td>4372</td>
<td>2100</td>
<td>4400</td>
</tr>
<tr>
<td>Lead</td>
<td>2160</td>
<td>700</td>
<td>2290*</td>
</tr>
<tr>
<td>Zinc Alloy</td>
<td>X</td>
<td>X</td>
<td>4420*</td>
</tr>
</tbody>
</table>

(Shin et al., JKSNT, 2008)
• Poisson’s ratio was obtained from the wave speed values.

<table>
<thead>
<tr>
<th>Material</th>
<th>Reference [5]</th>
<th>Contact method</th>
<th>Immersion method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Nitride</td>
<td>0.18</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Steel</td>
<td>0.29</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.33</td>
<td>0.33</td>
<td>0.34</td>
</tr>
<tr>
<td>Brass</td>
<td>0.35</td>
<td>0.35</td>
<td>0.38</td>
</tr>
<tr>
<td>Copper</td>
<td>0.34</td>
<td>0.34</td>
<td>0.39</td>
</tr>
<tr>
<td>Lead</td>
<td>0.44</td>
<td>0.46</td>
<td>X</td>
</tr>
<tr>
<td>Zinc Alloy</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

(Shin et al., JKSNT, 2008)
Nondestructive measurement

\[ \mu = -\frac{\varepsilon_{22}}{\varepsilon_{11}} = \frac{\lambda}{2(\lambda + G)} \]

\[ c_t^2 = \frac{\lambda + 2G}{\rho} \quad \text{and} \quad c_l^2 = \frac{G}{\rho} \]

\[ \mu = \frac{1 - 2\alpha^2}{2 - 2\alpha^2} \]

\[ \alpha = \frac{c_t}{c_l} : \text{ratio of transverse and longitudinal wave speeds} \]
Poisson’s ratio scanning using immersion UT

- Velocity ratio can be obtained without the knowledge of specimen thickness.
- Mu-scan was proposed.
What is good about Immersion UT

- Simultaneous measurement of two wave velocities from mode converted signals.
- Uses single transducer.
- Having no couplants makes free scan.
- Fast scan over large surface area.
- Velocity ratio can be obtained without prior information of specimen thickness.
Work scope

- Feasible study for field application of mu-scan.
- Poisson’s ratio reflects microstructure of materials.
- Mu scan applied to material characterization.
- Specimen was welded zone.
Equipments

- Transducer
- Motion controller
- System controller
- Pulsar Receiver
- Step motors
Welded specimen

- Double-V-grooved Carbon-steel.
- Water jet cutting (in order to avoid thermal change of microstructure)
- natural stain
- Unknown welding condition.
Typical wave form

- 3P1S is clearer than 1P1S
Peak search algorithm

- Gaussian filter (identify each echo)
- Threshold (large/small echo)
- Classify normal and abnormal signals
- Nullification for abnormal signals
Range
– 0.26~0.32 about 20% variation
Mu-scan of weldment 2

- Similar pattern
- Welded zone can be distinguished from the base metal.
Mu-scan of weldment 3
Conclusions

• 3P1S signal offers clearer information than 1P1S signal.
• Welded zone is well distinguished from base metal.
• Mu-scan shows high potential to characterize materials.
Future works

- Comparison of mu-scan with microstructure and micro-hardness test
- Why 3P1S? → theoretical analysis
- Relationship between mu-scan and test conditions, such as, thickness of specimen, frequency, diameter of the transducer.
- Application to other materials
  - Sintered ceramics uniformity testing.


Poisson's Ratio Scanning Using Immersion Ultrasonic Testing

Jin-Ha Park  Seo-Young Oh  Young H. Kim  Seung S. Lee