### Introduction
- 35% of all asphalt concrete placed by Caltrans must, by law, contain recycled tire rubber. Rubber is added to the asphalt primarily using the wet-process to produce rubberized hot mix asphalt (R HMAC).
- Quality control of the binders is determined by viscosity only, and no performance grading system is being used.
- Due to the presence of relatively large rubber particles (100% pass the 2.36mm sieve) in the binder, the parallel plate testing system with either 1 mm or 2 mm gaps specified in the Superpave Performance Grading System is not appropriate for measuring the rubberized binder properties.
- These large rubber particles are more likely to contact the plates with the resulting measurement potentially being dominated by the rheology of the rubber particles rather than the binder.
- A concentric cylinder testing geometry was investigated and compared to traditional parallel plates with a view to using this for quality control of asphalt rubber binders.
- The first phase of the study compared the two geometries with conventional binders.

### Concentric Cylinder Geometry (Cup & Bob)
- Concentric cylinder geometry has been widely used to measure the viscosity of materials with fine particulates.
- Only limited research has been undertaken using this geometry to measure G* of 6 of asphalt binders.
- The geometry is controlled by the surface area of the bob and the inside surface area and radius of the cup.

### Calibration of Conversion Factor (Cg)

\[
\tau = \frac{T}{2\pi LR^2} \quad \gamma = \frac{\theta R_g}{(R-R_p)}
\]

**Larger gap concentric cylinders:**
- The linear assumption of shear stress between the two cylinders is no longer appropriate.
- Binder-specific conversion factors need to be determined based on the complex viscosity, angular frequency, strain, and torque of the asphalt binders.

\[
C_{g_{R}} = \frac{\eta_{yy}(100)}{\tau}
\]

### Results

**Testing with Binder Specific Conversion Factors**

### Table 1: ANOVA Results of G* (kPa) with Varying Conversion Factors on Conventional Binders

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Source Type</th>
<th>Source</th>
<th>G* (kPa)</th>
<th>F Value</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>Cup &amp; Bob</td>
<td>Bob</td>
<td>0.0080</td>
<td>0.0054</td>
<td>&lt;2e-16</td>
</tr>
<tr>
<td>Geometry</td>
<td>Cup &amp; Bob</td>
<td>Residual</td>
<td>0.0059</td>
<td>2.3652</td>
<td>&lt;2e-16</td>
</tr>
</tbody>
</table>

### Results for Modified Binders

**Table 2: ANOVA Results of G* (kPa) with Varying Conversion Factors on Modified Binders**

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Source Type</th>
<th>Source</th>
<th>G* (kPa)</th>
<th>F Value</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>Cup &amp; Bob</td>
<td>Bob</td>
<td>0.0065</td>
<td>0.0042</td>
<td>&lt;2e-16</td>
</tr>
<tr>
<td>Geometry</td>
<td>Cup &amp; Bob</td>
<td>Residual</td>
<td>0.0053</td>
<td>1.2006</td>
<td>&lt;2e-16</td>
</tr>
</tbody>
</table>

### Summary
- No statistically significant difference was found between the results from the two geometries when using a varied Cs.
- No significant difference was found between the results from the two geometries when testing conventional binders.
- A statistically significant difference was found between the results of RTFO and TFO aged binders after testing with both geometries. RTFO aging was more severe than TFO aging.