Comparison of Concentric Cylinder and Parallel Plate Geometries for Asphalt Binder Testing using a Dynamic Shear Rheometer

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Caltrans

Introduction

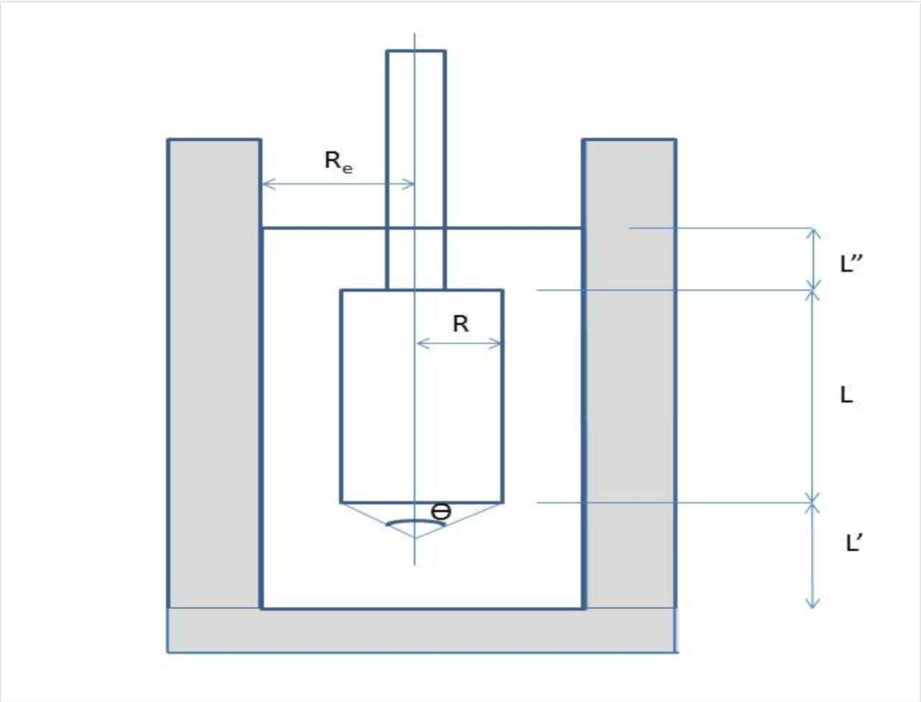
- 35% of all asphalt concrete placed by Caltrans must, by law, contain recycled tire rubber. Rubber is added to the asphalt primarily using the wet-process to produce rubberized hot mix asphalt (RHMA).
- Quality control of the binders is determined by viscosity only, and no performance grading system 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* and δ of asphalt binders.
- The geometry is controlled by the surface area of the bob and the inside surface area and radius of the cup.

$$\tau = \frac{T}{2\pi L R^2} \qquad \gamma = \frac{\theta R_e}{(R - R_e)}$$

Concentric Cylinder Geometry (Cup & Bob)



Advantages:

- Able to measure rheological properties of rubberized binders with relatively large crumb rubber particles.
- No trimming is required prior to testing.
- Good temperature control of the sample is guaranteed (relatively large contact area around the wall of the cup).

Disadvantages:

- A relatively large amount of sample (25 g) is required.
- Takes about twice the time compared to parallel plates. However, this can be offset by using DSR manufacturer-approved disposable cups, which reduces equipment cleaning time.

Calibration of Conversion Factor (C_{ss})

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.

$$C_{ss} = \frac{\eta[\omega(\gamma/100)]}{T}$$

Results

Testing with Binder Specific Conversion Factors

- **Conventional Binders**

TABLE 1: ANOVA Results of G*/sin(δ) with Varied Conversion Factor on Conventional Binders (α=0.05)

Variables	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Geometry	1	0.0006	0.0006	0.294	0.59
Source	2	0.9808	0.4904	240.582	<2e-16
Residuals	50	0.1019	0.0020	-	-

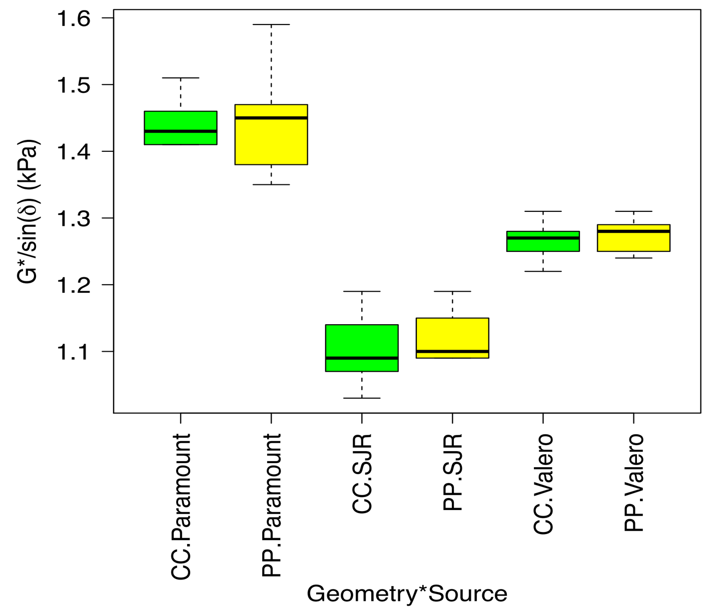


FIGURE 2a: Conventional binder: G*/sin(δ) with varied conversion factor at 64°C.

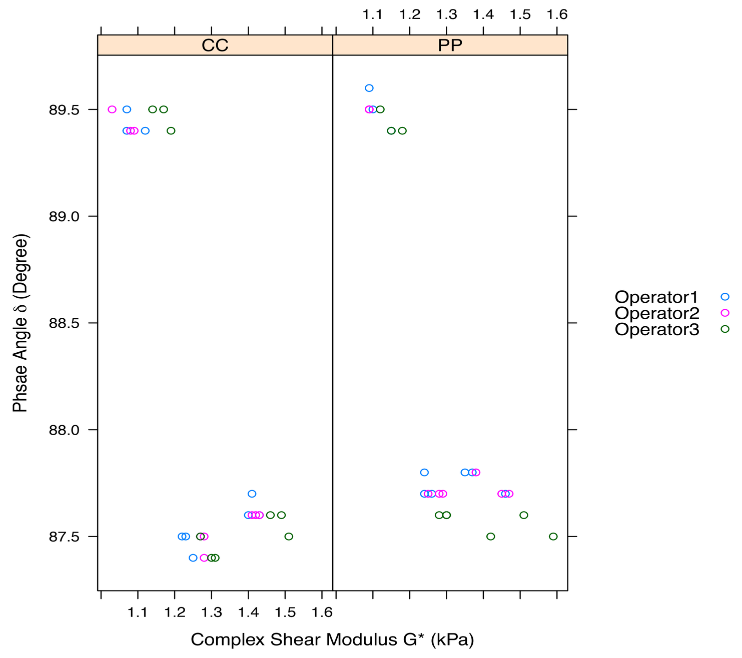


FIGURE 2b: Conventional binder: G* against δ with varied conversion factor at 64°C.

- **Modified Binders**

TABLE 1: ANOVA Results of G*/sin(δ) with Varied Conversion Factor on Modified Binders (α=0.05)

Variables	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Geometry	1	0.09	0.089	0.090	0.7650
Binder Type	1	4.46	4.459	4.518	0.0391
Residuals	45	44.41	0.987		

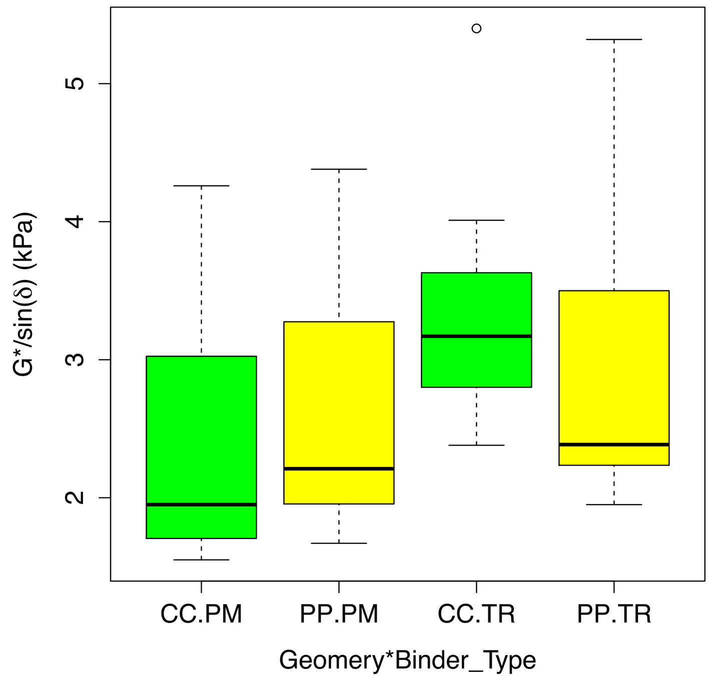


FIGURE 3a: Modified binders: G*/sin(δ) with varied conversion factor at64 °C.

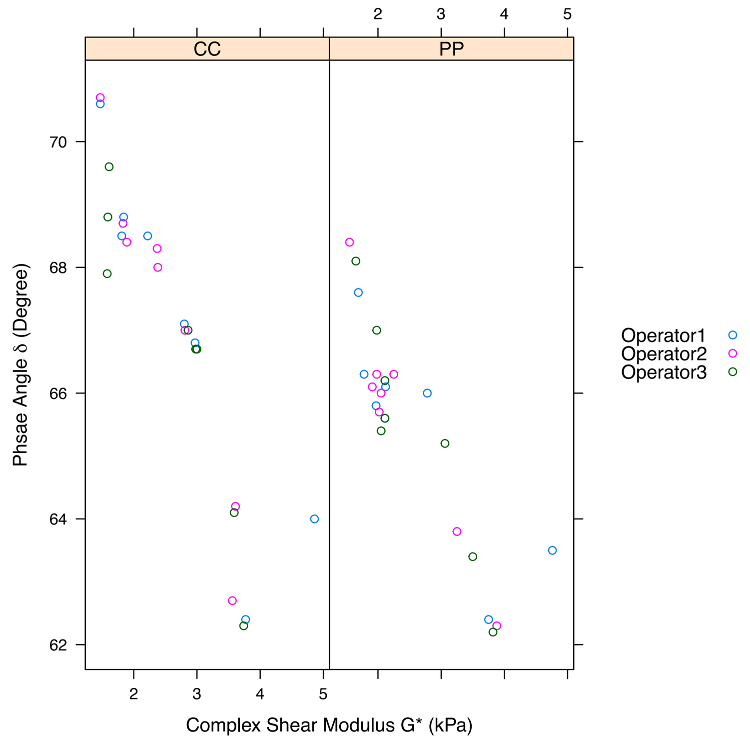


FIGURE 3b: Modified binders: G* against δ with varied conversion factor at 64°C.

Results

- **RTFO Aged Binders**

TABLE 1: ANOVA Results of G*/sin(δ) with Varied Conversion Factor on RTFO Aged Binders (α=0.05)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Geometry	1	0.013	0.013	0.064	0.802
Binder Type	2	15.403	7.701	39.254	1.19e-07
Residuals	20	3.924	0.196		

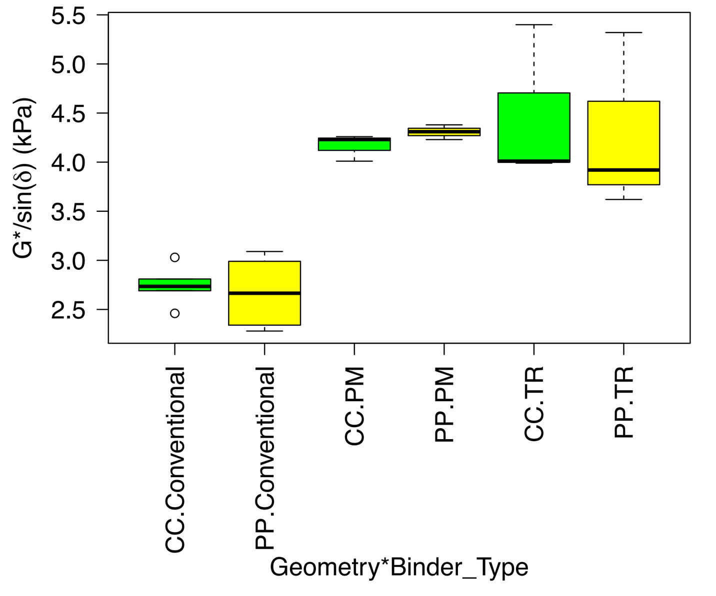


FIGURE 4a: RTFO aged binders: G*/sin(δ) with varied conversion factor at 64°C.

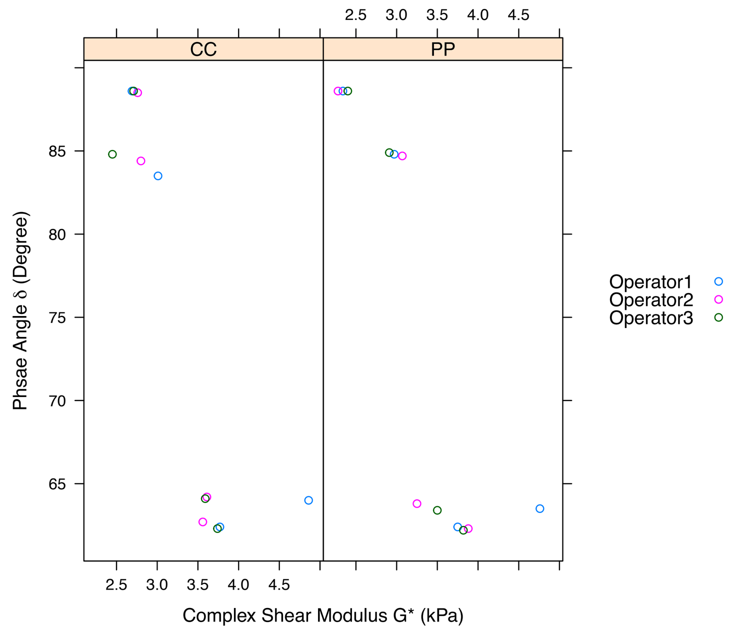


FIGURE 4b: RTFO aged binders: G* against δ with varied conversion factor at 64°C.

Testing with Fixed Conversion Factors

TABLE 1: ANOVA Results for the Comparison of Two Geometries (α = 0.05)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Geometry	1	0.033	0.033	1.223	0.274
Aging Condition	2	17.150	8.575	315.280	<2e-16
Residuals	50	1.360	0.027		

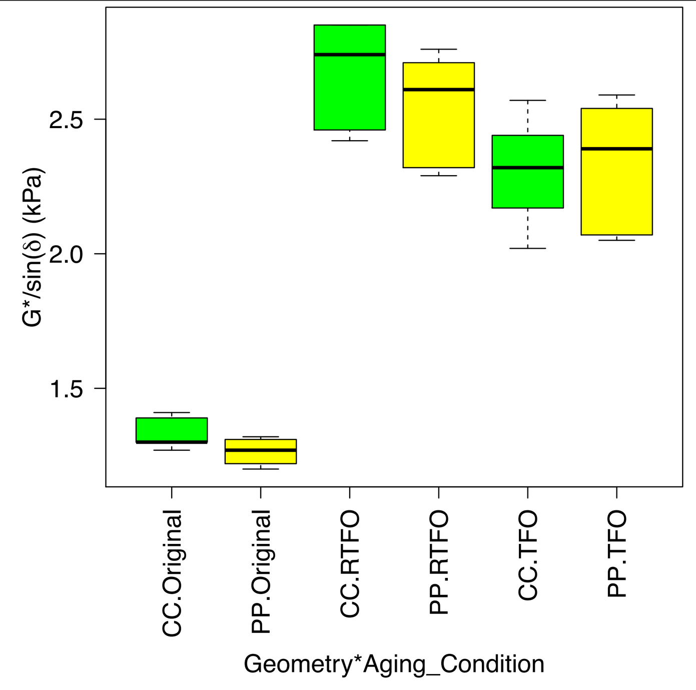


FIGURE 5a: G*/sin(δ) with fixed conversion factor at 58°C, 64°C, and 70°C on unaged and aged binders.

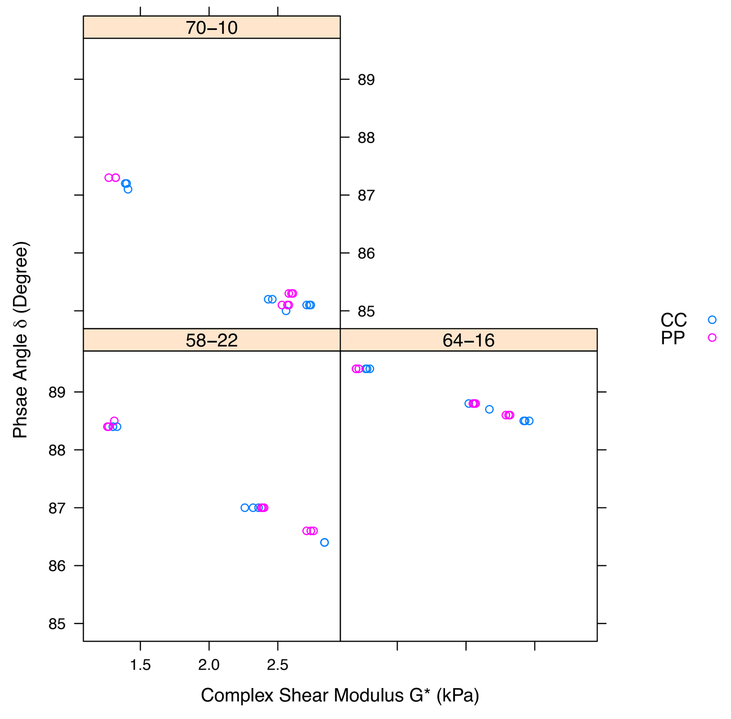


FIGURE 5b: G* against δ with fixed conversion factor at 58°C, 64°C, and 70°C on unaged and aged binders.

Summary

- No statistically significant difference was found between the results from the two geometries when using a varied Css.
- 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. RFTO aging was more severe than TFO aging.