

## A Case Study to Evaluate the Effect of CBp Modification on $G^*/\sin(\Delta)$

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### Abstract

Many researchers have studied Carbon black's (CB) performance-enhancement of asphalt pavement mixtures, such as improved rutting and wear resistance and reduction of temperature susceptibility, age hardening, and stripping potential. This study analyzes the effect of CBp modification on Dynamic Shear Rheometer (DSR) results for the original binder, which meets requirements for PG 64-22. Four different CBp modification levels were used, each blend was tested at four different temperatures, and for each condition three different replicates were tested. The relation between DSR test temperature and  $G^*/\sin(\delta)$  values were established for the four CBp modification levels and regression equations and  $R^2$  values were estimate, using the power function regression equation in each case. Based on the regression equations the relation between DSR test temperature and  $G^*/\sin(\delta)$  values were estimated for each modification level. CBp modification increased the  $G^*/\sin(\delta)$  values for each modification level. The relation between the CBp modification level and the  $G^*/\sin(\delta)$  values were also established. The results of this study indicate that as CB amount in a blend increases, stiffness of the binder increases. In this study it is found that as the CBp modification increased, the  $G^*/\sin(\delta)$  values also increased for each modification level.

Carbon black has been widely studied by researchers as a performance-enhancing additive in asphalt pavement mixes. Carbon black apparently improves rutting resistance (Yao et al. 1986, Khosla 1991, Fader 2004, and Park et al. 1997), reduces temperature susceptibility (Rostler et al. 1977, Vallerga 1980, Khosla 1991, and Fader 2004), reduces age hardening (Rostler et al. 1977), reduces stripping potential (Fader 2004 and Park et al. 1997), and improves wear resistance (Vallerga 1980).

The objective of this study is to analyze the effect of CBp modification on DSR results for the original binder. In this study Dynamic Shear Rheometer (DSR) was used to evaluate binder properties for different levels of CBp modification. The CBp used in this research is light black in color and was provided by CBp Carbon Industries Inc., Netherlands. Binder used in this study was provided by Holly Asphalt located in Glendale, Arizona. The binder meets the requirements for PG 64-22. Table 2 summarizes test results on the original binder used in this study.

Table 2. Superpave Binder Tests Results for PG 64-22

PG 64-22		Test Results	Requirement
Original	$G^*/\sin\delta$	1.44 kPa	Minimum 1.00 kPa
RTFO	$G^*/\sin\delta$	3.83 kPa	Minimum 2.20 kPa
PAV	$G^*\sin\delta$	4261 kPa	Maximum 5000 kPa
PAV	S	175 MPa	Maximum 300 MPa
PAV	m-value	0.333	Minimum 0.300

Four different CBp modification levels, 0%, 4%, 8% and 12%, were utilized for this study. Each blend was tested at four temperatures: 58°C, 64°C, 70°C, and 76°C. For each condition three replicates were tested. Table 1 shows the experimental design for this study.

Table 1. Experimental Design

Modification Levels	Test Temperatures			
	58°C	64°C	70°C	76°C
0%	3	3	3	3
4%	3	3	3	3
8%	3	3	3	3
12%	3	3	3	3

For this study a total of 48 DSR tests were conducted. Results summarizing  $G^*$  values, phase angle,  $G^*/\sin(\delta)$ , and strain amplitude were included in the Appendix and in Tables A1 through A4, respectively.

First, the relation between DSR test temperature and  $G^*/\sin(\delta)$  values were established for four CBp modification levels. Figures A1 through A4 shows the  $G^*/\sin(\delta)$  values versus test temperature graphs. Then the regression equations and  $R^2$  values were estimated for each graph. In each case the power function regression equation was used, and very high  $R^2$  values were observed. Table 3 summarizes the regression equations and  $R^2$  values.

Table 3. Regression equations and  $R^2$  values

CBp Modification	Regression Equations	$R^2$
0%	$Y=1E+18x^{-8.28}$	0.9988
4%	$Y=1E+18x^{-8.19}$	0.9955
8%	$Y=9E+17x^{-8.14}$	0.9986
12%	$Y=4E+17x^{-7.92}$	0.9976

Based on the regression equations the relation between DSR test temperature and  $G^*/\sin(\delta)$  values were estimated for each modification level. The values were included in Appendix Table A5. As evident in Table A5, CBp modification increased the  $G^*/\sin(\delta)$  values for each modification level.

To further understand the effect of CBp modification on the binder properties, the relation between the CBp modification level and the  $G^*/\sin(\delta)$  values were established. Figure 1 shows the relation between  $G^*/\sin(\delta)$  and CBp modification level at 70°C. The  $G^*/\sin(\delta)$  values on the original binder should be at a minimum of 1.00 kPa to satisfy the Performance Grading criteria. This criterion is marked on the graph as a red line. A power regression equation with an  $R^2$  value of 0.8986 was utilized for this graph. Based on the regression equation, binder can meet the  $G^*/\sin(\delta)$  criteria for the original binder at 70°C and at a 11.3% CBp modification level.

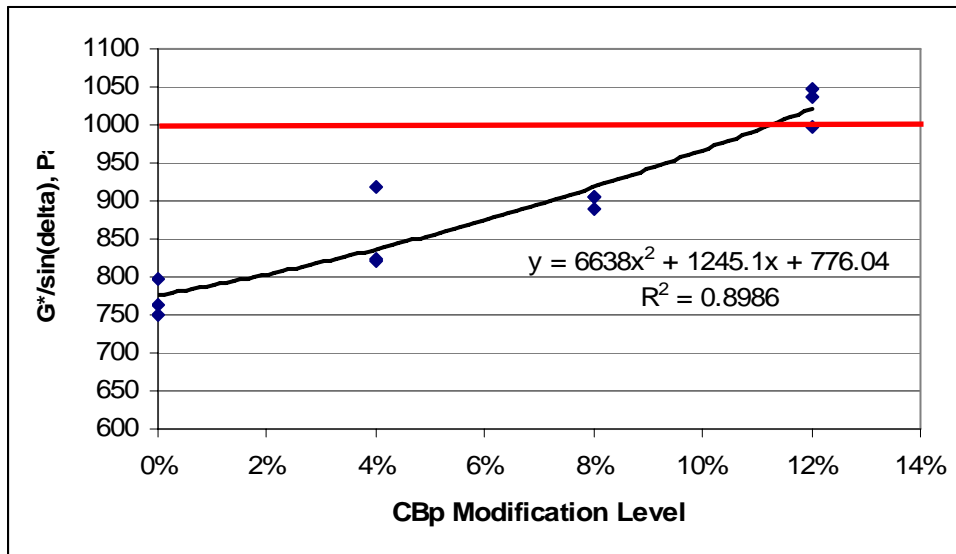


Figure 1. Effect of CBp modification on  $G^*/\sin(\delta)$  at 70°C

The results of this study indicated that as the amount of CB in the blend increases, the stiffness of the binder increases. In this study only intermediate temperature binder properties are evaluated through  $G^*/\sin(\delta)$  criteria. In this case study it is found that as the CBp modification increased, the  $G^*/\sin(\delta)$  values also increased for each modification level. It is estimated that with the 11.3% CBp modification, the PG 64-22 binder used in this study would satisfy the  $G^*/\sin(\delta)$  criteria at 70°C for the original binder. The properties of the binder at high and low temperatures should also be evaluated for a better performance analysis. The increase in binder stiffness at high temperatures is a positive effect since resistance to permanent deformation is increased.

**Reference:**

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## Appendix

Table A1. Modulus ( $G^*$ ) values

<b>Modulus (<math>G^*</math>), [Pa]</b>				
Modification	<b>58°</b>	<b>64°</b>	<b>70°</b>	<b>76°</b>
<b>0%</b>	3.5625E+03	1.6378E+03	7.6231E+02	3.7530E+02
<b>0%</b>	3.5697E+03	1.5933E+03	7.4866E+02	3.7124E+02
<b>0%</b>	3.5139E+03	1.6895E+03	7.9764E+02	3.9679E+02
<b>4%</b>	3.7295E+03	1.6885E+03	8.2162E+02	4.4006E+02
<b>4%</b>	4.0678E+03	1.7935E+03	8.2361E+02	4.0686E+02
<b>4%</b>	4.2519E+03	1.8983E+03	9.1911E+02	4.7637E+02
<b>8%</b>	3.9976E+03	1.8304E+03	8.8830E+02	4.6919E+02
<b>8%</b>	4.4230E+03	1.9814E+03	9.0487E+02	4.5104E+02
<b>8%</b>	4.1055E+03	1.8668E+03	9.0465E+02	4.7651E+02
<b>12%</b>	4.1981E+03	2.0193E+03	9.9683E+02	5.4681E+02
<b>12%</b>	4.9319E+03	2.1679E+03	1.0365E+03	5.2249E+02
<b>12%</b>	4.5152E+03	2.1046E+03	1.0478E+03	5.3616E+02

Table A2. Phase angle ( $\delta$ ) values

<b>Phase Angle, [<math>\delta</math>]</b>				
Modification	<b>58°</b>	<b>64°</b>	<b>70°</b>	<b>76°</b>
<b>0%</b>	85.80	87.30	88.30	89.00
<b>0%</b>	85.80	87.40	88.50	89.20
<b>0%</b>	85.60	87.40	88.50	89.20
<b>4%</b>	85.90	87.40	88.30	89.10
<b>4%</b>	86.20	87.40	88.80	89.10
<b>4%</b>	86.10	87.30	88.20	89.30
<b>8%</b>	86.10	87.90	88.70	89.30
<b>8%</b>	86.20	87.80	88.70	89.10
<b>8%</b>	86.10	87.40	88.80	89.60
<b>12%</b>	86.60	87.70	89.00	89.70
<b>12%</b>	86.70	87.90	88.60	89.20
<b>12%</b>	86.30	87.70	88.90	89.00

Table A3. G\*/sin(delta) values

<b>G*/sin(delta), [Pa]</b>				
Modification	<b>58°</b>	<b>64°</b>	<b>70°</b>	<b>76°</b>
<b>0%</b>	3.5721E+03	1.6369E+03	7.6266E+02	3.7536E+02
<b>0%</b>	3.5792E+03	1.5933E+03	7.4892E+02	3.7128E+02
<b>0%</b>	3.5241E+03	1.6913E+03	7.9790E+02	3.9683E+02
<b>4%</b>	3.7389E+03	1.6902E+03	8.2199E+02	4.4011E+02
<b>4%</b>	4.0770E+03	1.7954E+03	8.2379E+02	4.0691E+02
<b>4%</b>	4.2618E+03	1.9004E+03	9.1955E+02	4.7641E+02
<b>8%</b>	4.0068E+03	1.8317E+03	8.8852E+02	4.6922E+02
<b>8%</b>	4.4325E+03	1.9828E+03	9.0510E+02	4.5110E+02
<b>8%</b>	4.1149E+03	1.8687E+03	9.0486E+02	4.7652E+02
<b>12%</b>	4.2054E+03	2.0208E+03	9.9698E+02	5.4682E+02
<b>12%</b>	4.9401E+03	2.1693E+03	1.0368E+03	5.2254E+02
<b>12%</b>	4.5246E+03	2.1063E+03	1.0480E+03	5.3624E+02

Table A4. Strain Amplitude values

<b>Strain Amplitude, [%]</b>				
Modification	<b>58°</b>	<b>64°</b>	<b>70°</b>	<b>76°</b>
<b>0%</b>	12.47	11.70	11.81	11.94
<b>0%</b>	11.96	11.97	12.21	11.92
<b>0%</b>	11.67	12.55	11.98	12.15
<b>4%</b>	11.56	11.88	12.09	11.78
<b>4%</b>	11.69	11.69	12.07	12.21
<b>4%</b>	11.93	12.34	12.02	12.02
<b>8%</b>	12.01	12.32	12.18	11.80
<b>8%</b>	11.76	11.48	11.99	12.14
<b>8%</b>	12.39	12.47	12.17	11.98
<b>12%</b>	11.99	11.99	11.95	11.85
<b>12%</b>	12.19	12.57	11.96	11.90
<b>12%</b>	12.18	12.26	11.84	12.14

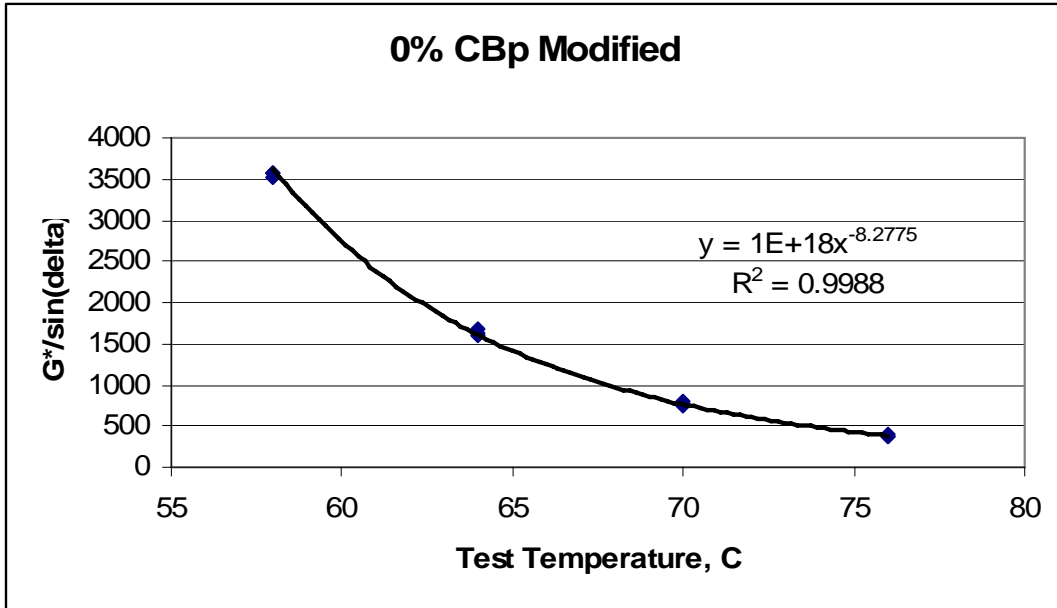


Figure A1.  $G^*/\sin(\delta)$  vs. Test Temperature for 0% CBp Modified Binder

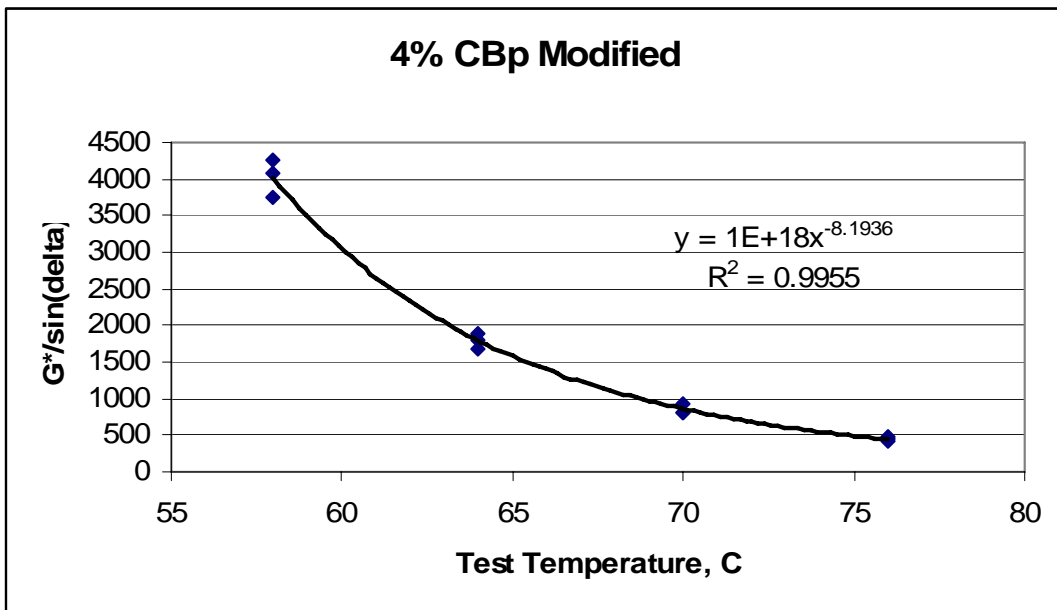


Figure A2.  $G^*/\sin(\delta)$  vs. Test Temperature for 4% CBp Modified Binder

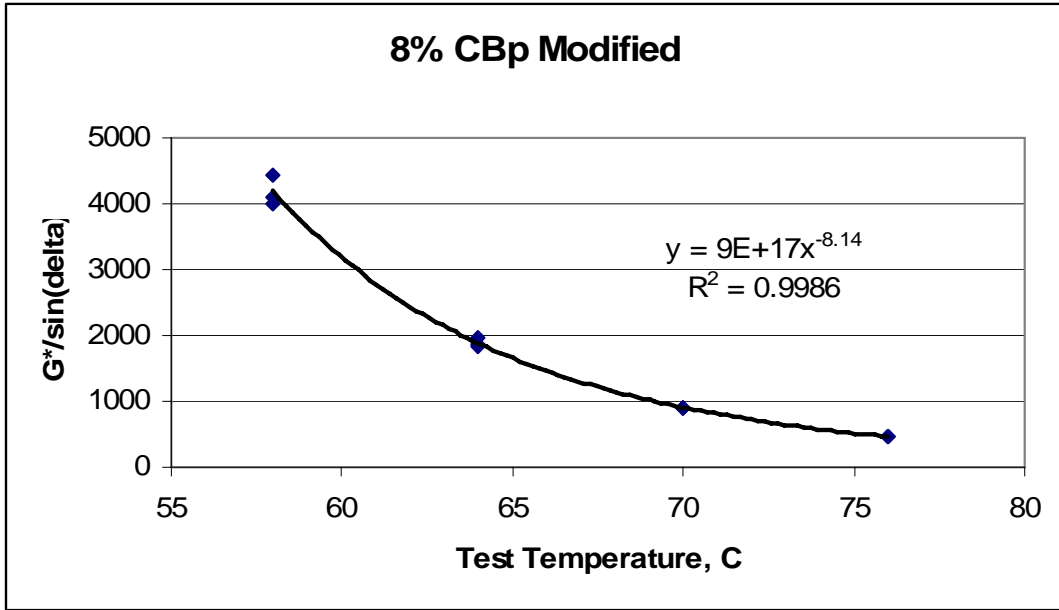


Figure A3.  $G^*/\sin(\delta)$  vs. Test Temperature for 8% CBp Modified Binder

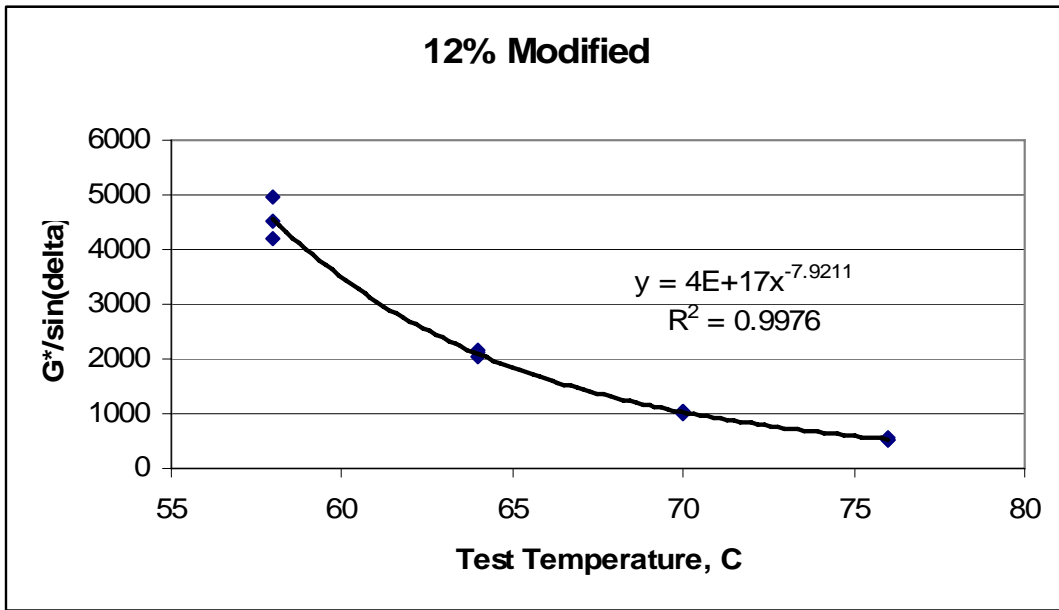


Figure A4.  $G^*/\sin(\delta)$  vs. Test Temperature for 12% CBp Modified Binder

Table A5. Estimated  $G^*/\sin(\delta)$  values

Test Temp., C	Modification Level			
	0%	4%	8%	12%
58	2530.6	3557.8	3980.5	4303.0
59	2196.7	3092.8	3463.4	3758.1
60	1911.4	2694.9	3020.6	3289.6
61	1667.0	2353.5	2640.3	2885.9
62	1457.1	2060.0	2313.0	2537.2
63	1276.3	1806.9	2030.5	2235.1
64	1120.3	1588.1	1786.2	1973.0
65	985.4	1398.7	1574.4	1745.0
66	868.4	1234.2	1390.4	1546.2
67	766.8	1091.1	1230.3	1372.6
68	678.3	966.4	1090.5	1220.6
69	601.1	857.4	968.3	1087.3
70	533.6	762.1	861.3	970.2
71	474.5	678.5	767.4	867.1
72	422.6	605.0	684.8	776.1
73	377.0	540.4	612.1	695.8
74	336.8	483.4	547.9	624.7
75	301.4	433.0	491.2	561.7
76	270.1	388.5	441.0	505.8