# MATERIAL'S VOLUMETRIC-FLOW RATE (MVR) :
# A USEFUL PARAMETER FOR UNIFICATION OF RHEOLOGICAL DATA AND QC/QA OF ASPHALT BINDERS

## DEFINITION OF MVR

The MVR is defined as the volume of the material (in milliliters or cubic centimeters) that is extruded in 10 minutes through the die of specific diameter and length as described above by applying pressure through dead weight under prescribed temperature conditions.

## EQUIPMENT FOR MVR MEASUREMENT

The MVR is determined through a closely defined flow measurement device (FMD), whose main parts are shown in Figure 1.

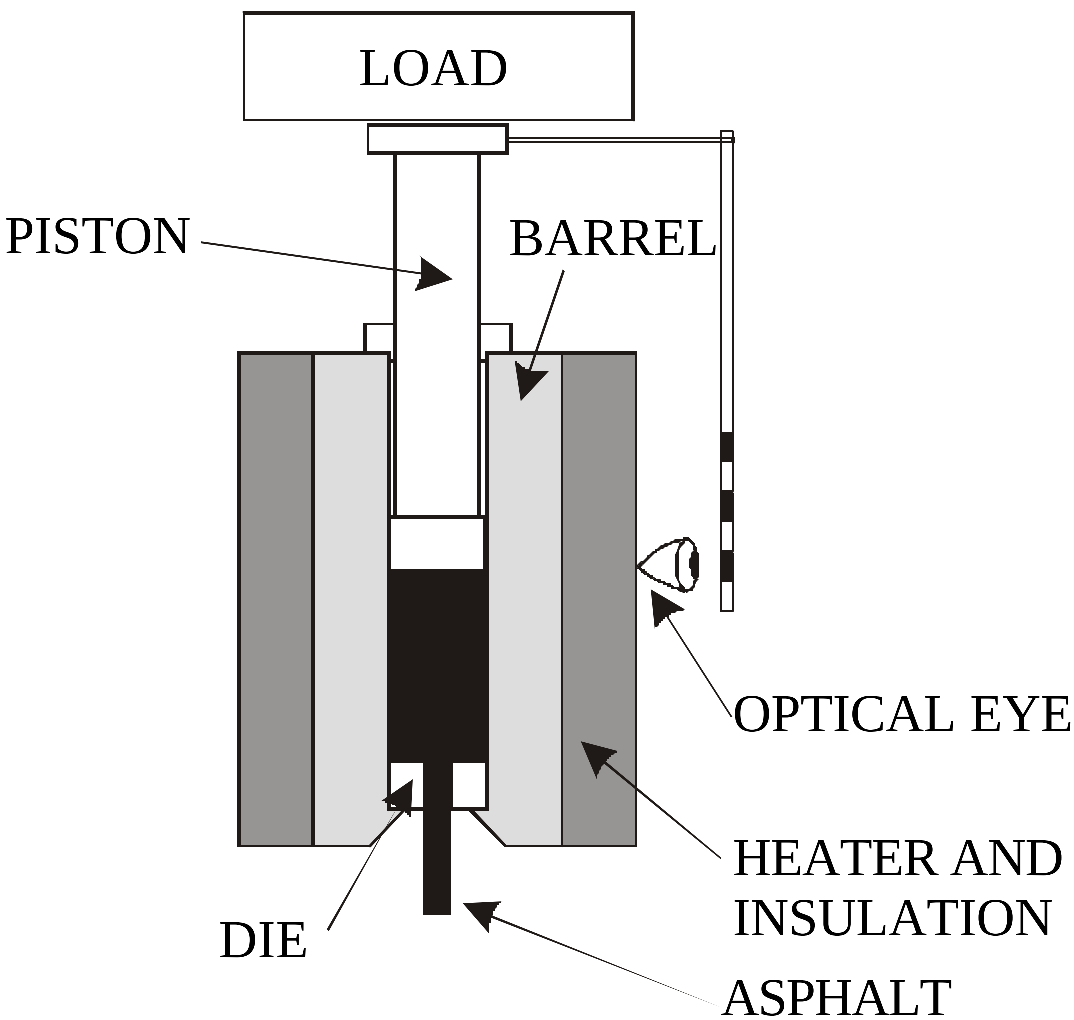


**Figure 1**

This equipment is borrowed from the polymer industry where it is routinely used to measure the melt flow index of the polymers. The cylinder of the flow measurement device is made of hardened steel and is fitted with heaters, insulated, and controlled for operation at the required temperature. The thermocouple is buried inside the instrument’s barrel. The thermocouple and the associated temperature control electronics are calibrated against NIST traceable temperature probes by the equipment manufacturer. The heating device is capable of maintaining the temperature at 10 mm above the die to within "0.2EC of the desired temperature during the test. The temperature of the barrel, from 10 mm to 75 mm above the top of the die, is maintained within "1% of the set temperature (EC). All this is followed in strict compliance with the ASTM D1238 stipulations. The piston is made of steel and the diameter of its head is 0.075"0.015 mm less than that of the internal diameter of the cylinder which is 9.5 mm. Extrusion of the material is done through a die made of hardened steel with an internal diameter of 2.095 " 0.005 mm.

## UNMODIFIED ASPHALTS

Using the MVR, the fundamental rheological data from the Dynamic Shear Rheometer (DSR) can be unified. It has been found that there is just one single curve for all unmodified asphalts for each rheological parameter such as |G*|, G” and |G*| / Sin*. The unified |G*| / Sin* curve for original unaged unmodified asphalts is shown in Figure 2.

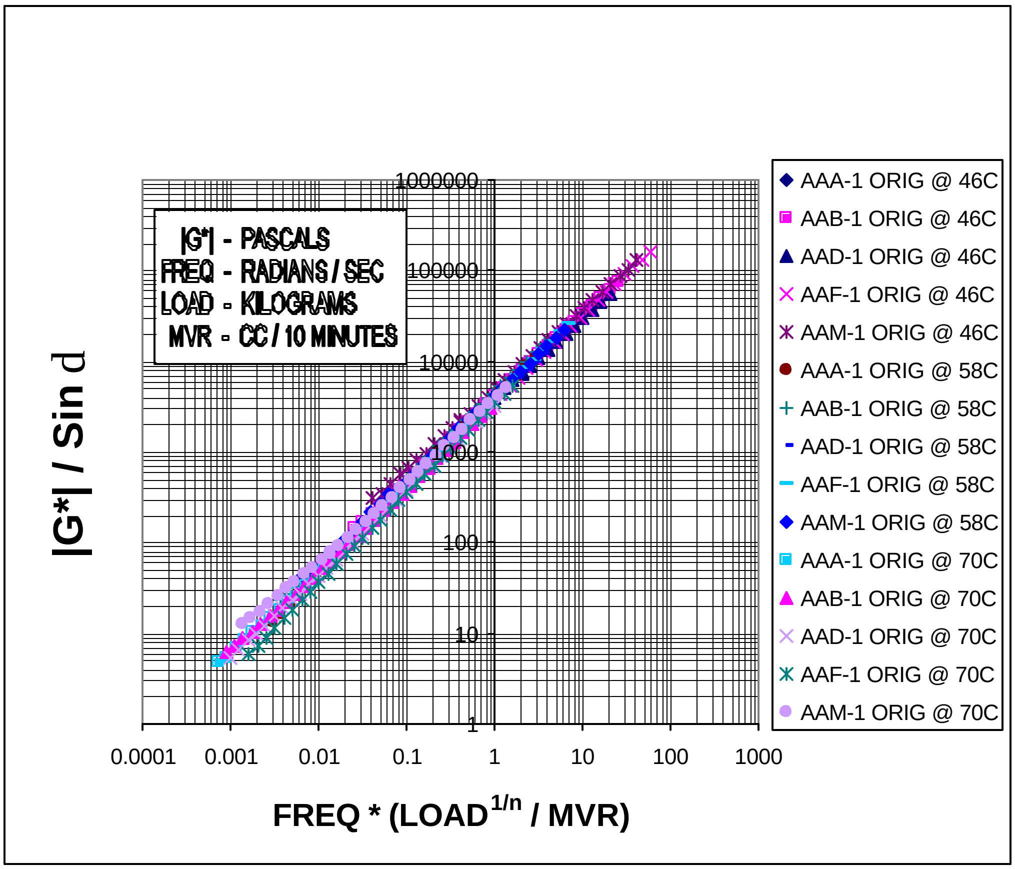


**Figure 2(a):** Unified curve of the SHRP parameter |G*| / Sin* with modified frequency T($L^{1/n}$/MVR) covering the temperature range of 46EC - 70EC for five asphalts (AAA-1, AAB-1, AAD-1, AAF-1 and AAM-1) each in original unaged forms.

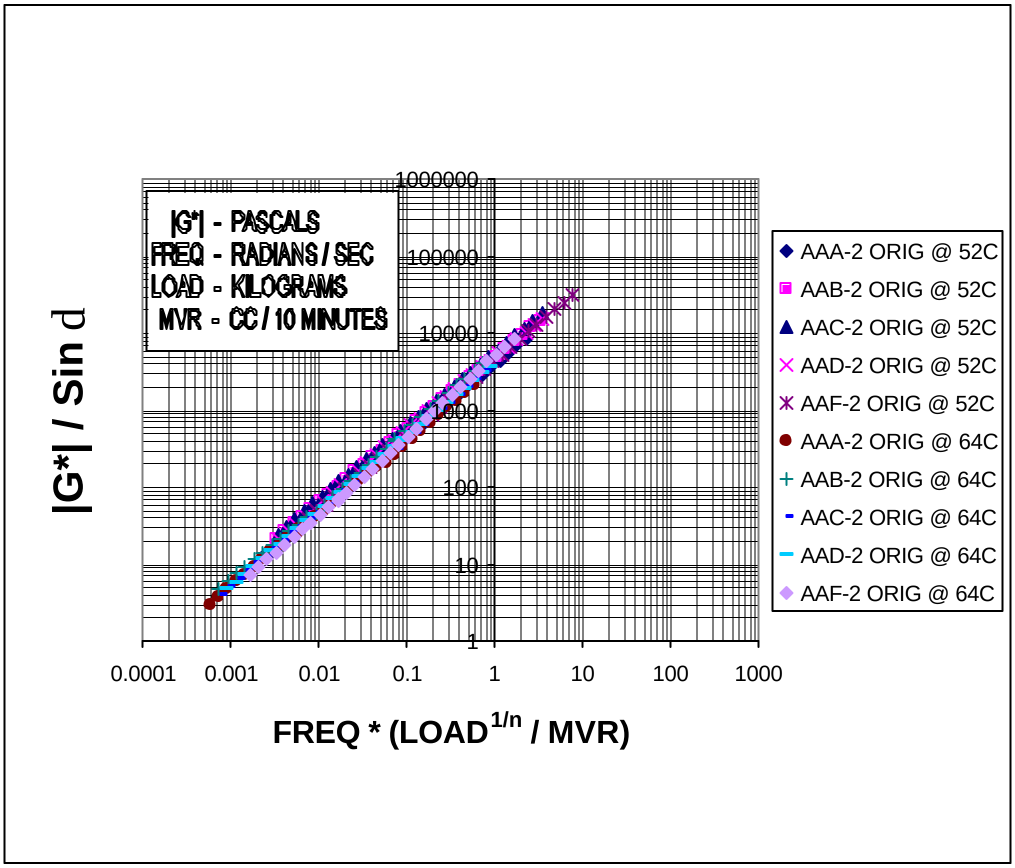


**Figure 2(b):** Unified curve of the SHRP parameter |G*| / Sin* with modified frequency T(L$^{1/n}$/MVR) covering the temperature range of 52EC - 64EC for five asphalts (AAA-2, AAB-2, AAC-2, AAD-2 and AAF-2) each in original unaged forms.

It should be noted that the unified curve in Figure 2(a) and the one in Figure 2(b) basically superimpose on each other though one is for dash1 type asphalts at temperatures of 46EC, 58EC, 70EC and the other is for dash2 type asphalt at temperatures of 52EC, 64EC.

Similar unified curves are obtained for |G*| as well as |G"| for all unmodified unaged asphalts, as well as for RTFOT and PAV aged unmodified asphalts.

The average value of rheological parameter at each (Load $^{1/n}$ /MVR) value in Figure 2(a) is used to form the theoretical unified curve for unmodified asphalts as shown in Figure 3.

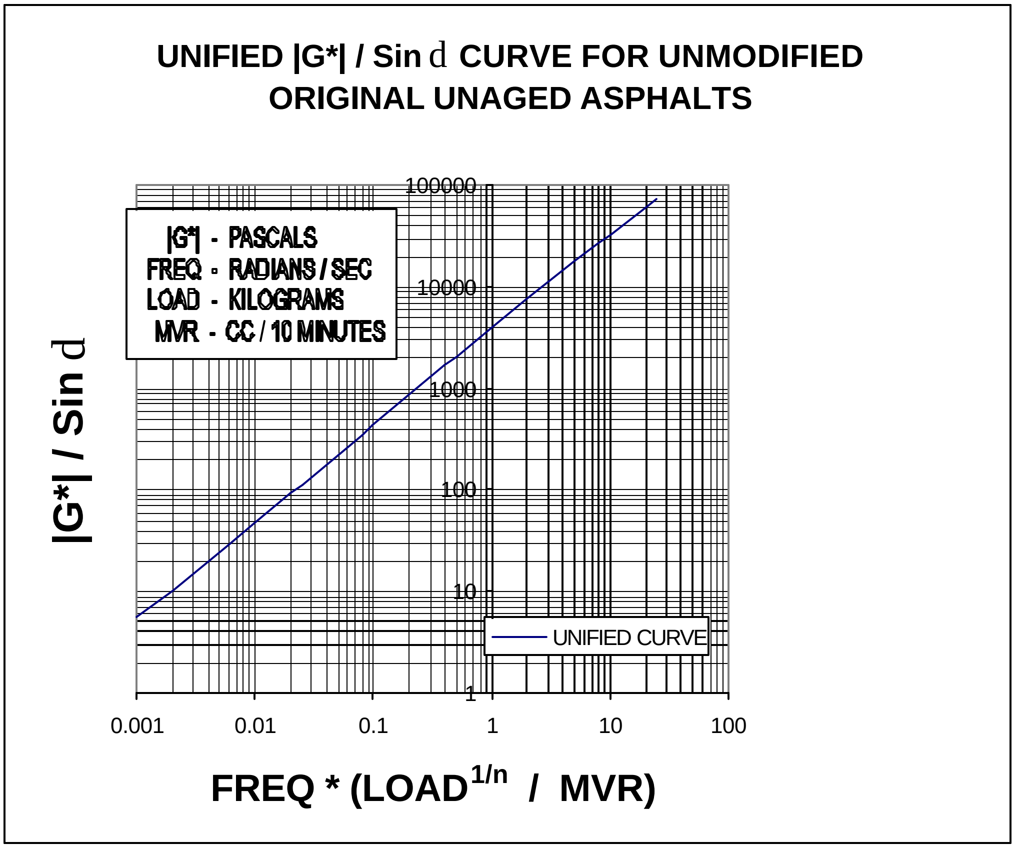


**Figure 3:** Unified curve of the SHRP parameter |G*| / Sin* with modified frequency T($L^{1/n}$/MVR) at temperatures of 46EC - 70EC for unmodified original unaged asphalts.

By determining the MVR value at any LOAD condition for an uncharacterized asphalt, Figure 3 can be used to predict the rheological behavior of the asphalt at the temperature of interest. Figure 4 shows the results of such prediction when compared with actual data.

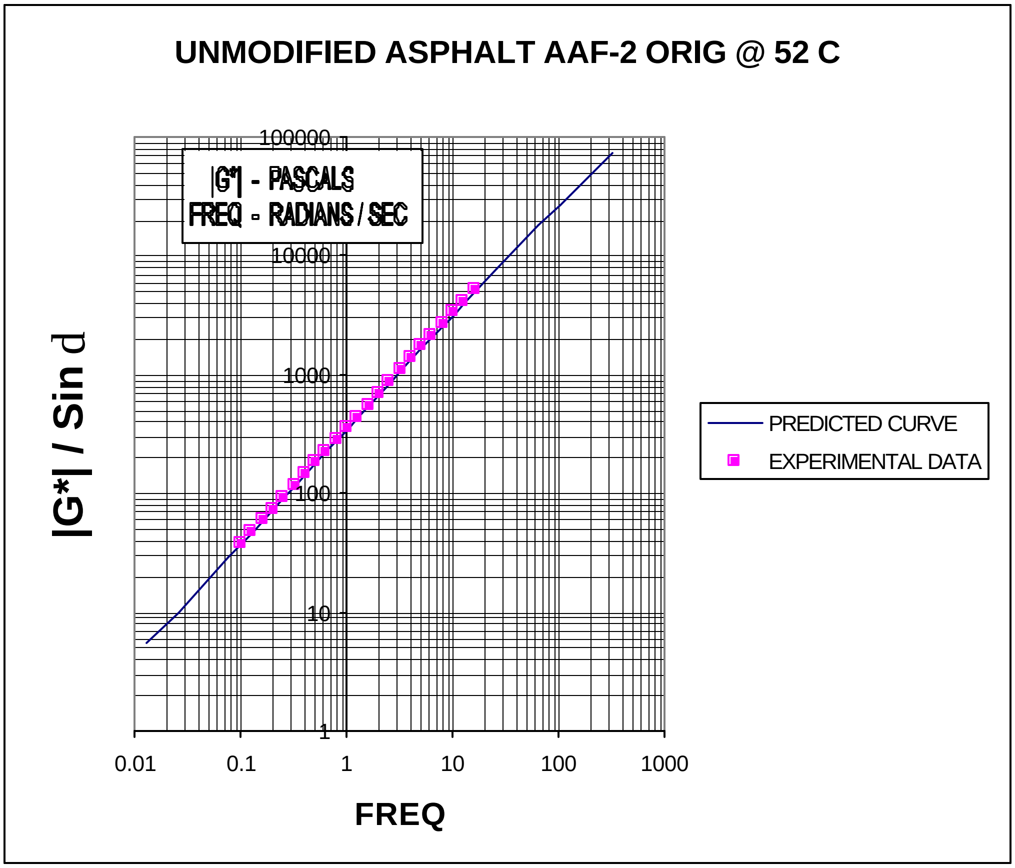


**Figure 4:** Comparison of the predicted curve and experimental data for the SHRP parameter |G*| / Sin * with frequency T at temperature of 52EC for unmodified original unaged asphalt AAF-2.

It should be noted that asphalt AAF-2 was not used when the theoretical unified curve was formed in Figure 3 using the average data from Figure 2(a).

## POLYMER-MODIFIED ASPHALTS

The idea of unification has been extended to polymer-modified asphalts. Presently, two specific polymer-modified asphalts have been tested, namely, Styrelf and Novophalt. It has been shown that unified curves can be obtained for each polymer-modified asphalt (for example, as in Figure 5) using the same method that was used for unmodified asphalts.

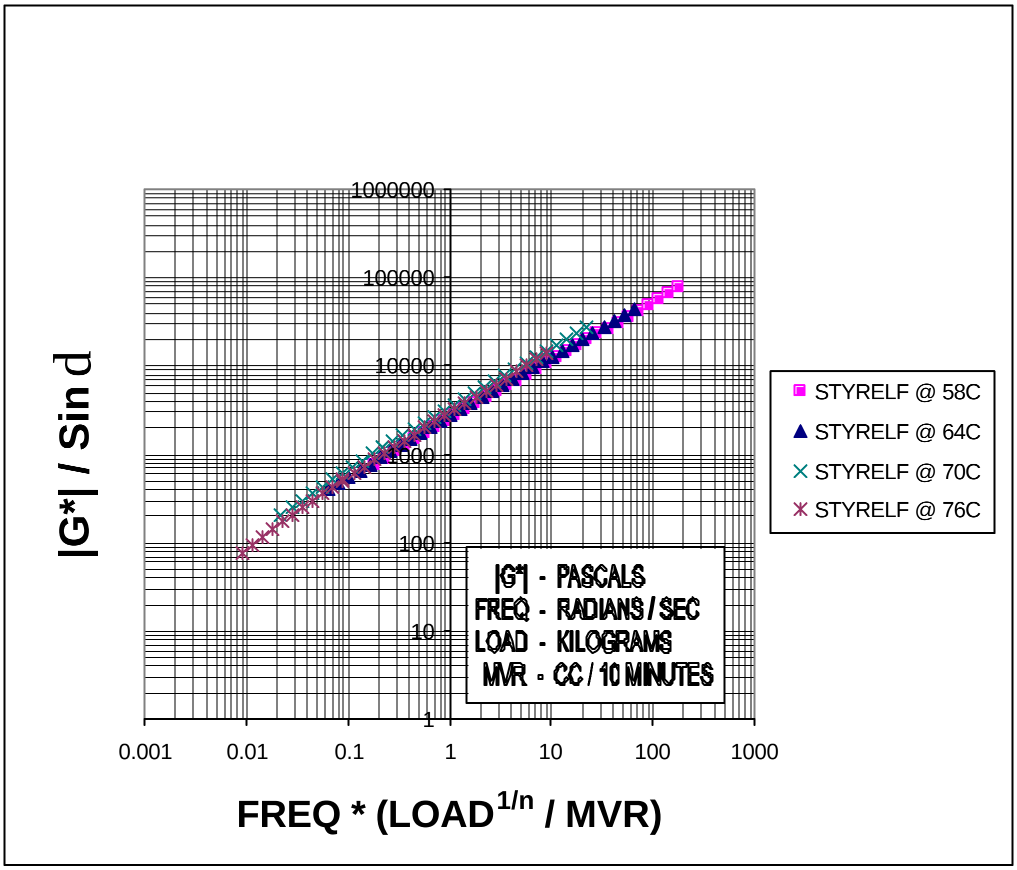


**Figure 5:** Unified curve of the SHRP parameter |G*| / Sin * with modified frequency T($L^{1/n}$/MVR) covering the temperature range of 58EC - 76EC for polymer-modified asphalt Styrelf in original unaged form.

Unified curve similar to that in Figure 5 is obtained for Novophalt using data at temperatures 52EC, 58EC, 70EC, 76EC. Using the average values of rheological parameter at each value of (Load $^{1/n}$ /MVR), the theoretical unified curve for Novophalt is formed as shown in Figure 6.

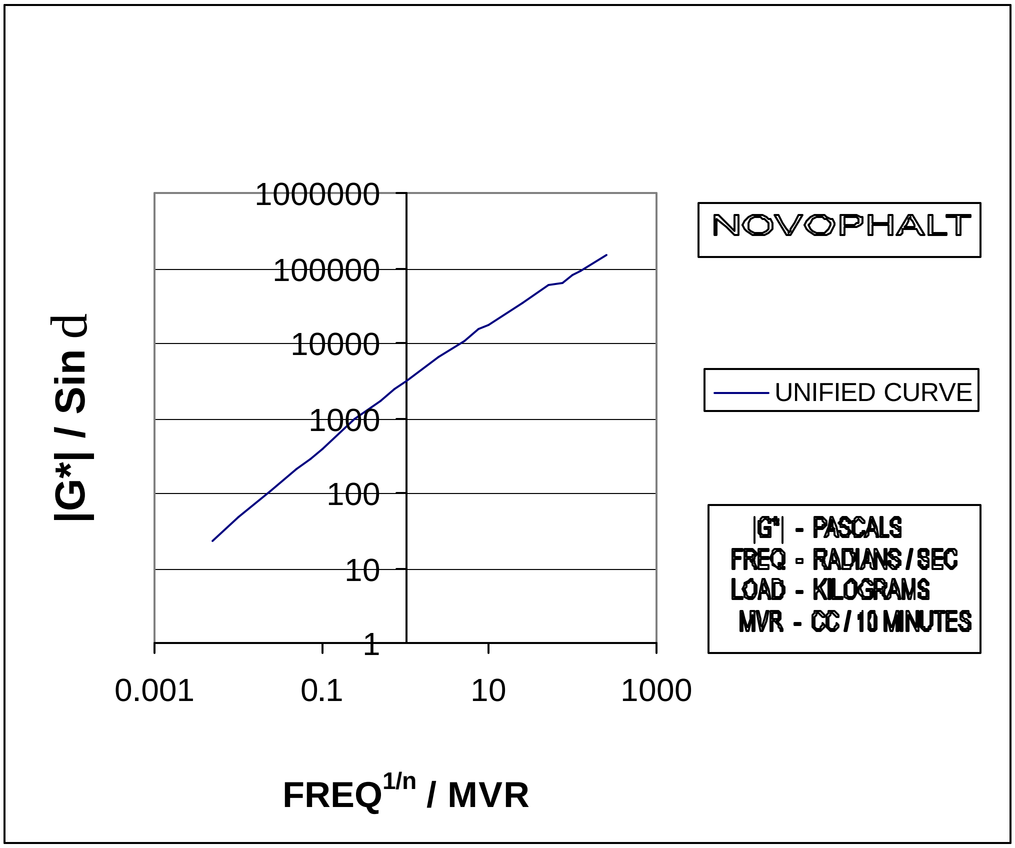


**Figure 6:** Unified curve of the SHRP parameter |G*| / Sin* with modified frequency T(L$^{1/n}$/MVR) at temperatures of 52EC - 76EC for polymer-modified asphalt - Novophalt.

Again, the unified curve can be used for predicting the rheological properties by determining only the MVR value at a LOAD condition at the temperature of interest. Figure 7 shows the results of such prediction when compared with actual data.

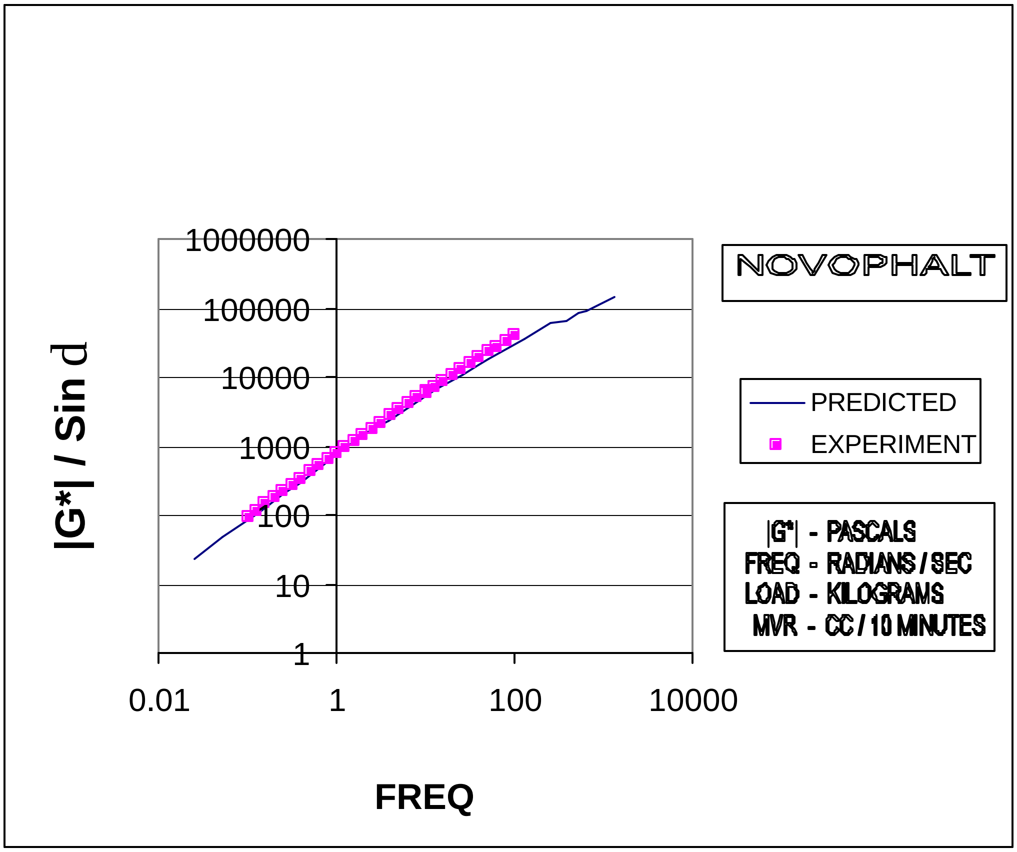


**Figure 7:** Comparison of the predicted curve and experimental data for the SHRP parameter |G*| / Sin * with frequency T at temperature of 64EC for polymer-modified asphalt - Novophalt.

It should be noted that data at 64EC was not used when the theoretical unified curve for Novophalt was formed in Figure 6 using the average data from Figure 5.

## HIGH TEMPERATURE PERFORMANCE GRADE

From the unified curves of unmodified and modified asphalts, a relationship ($L^{1/n}$ / MVR = 0.0245) was obtained which helps in the determination of the high temperature performance grade of the asphalts. A simplified version of the relationship was also proposed and it was shown that the high temperature performance grade corresponded to the temperature at which MVR = 50 when the load = 1.225 kg. It was also shown that by determining the MVR at two temperatures - one which is 6 degrees below the PG temperature and another which is 6 degrees above the PG temperature, the high temperature performance grade of the asphalts can be determined using the following equation.

$$T_{HS} = \left( \frac{T_1 T_2 (\ln MVR_{T_1} - \ln MVR_{T_2})}{T_1 \ln MVR_{T_1} - T_2 \ln MVR_{T_2} - (T_1 - T_2)\ln 50} \right) \qquad (1)$$

The results are shown in Table 1. The approach gives a very simple method of determining the high temperature performance grade using an inexpensive and portable simple flow measurement device (FMD). The MVR thus becomes an attractive parameter to be used for routine quality control as well as new product development of asphalt binders.

### TABLE 1- PG High Temperature Specifications Calculated by Different Methods

| Asphalt ID | PG High Temperatures, EC<br>@\|G*\|/Sin*=1 kPa<br>From DSR | @ $L^{1/n}$/MVR=0.0245<br>From FMD | @ MVR=50 for L=1.225 kg<br>From FMD | From<br>Eqn.(1) |
|---|---|---|---|---|
| Flux (PG52-34) | 55.84 | 56.08 | 55.82 | 56.02 |
| Base (PG64-28) | 67.62 | 66.91 | 66.48 | 66.50 |
| High (PG70-28) | 71.46 | 71.74 | 71.58 | 71.41 |
| Air-Blown (PG70-28) | 73.56 | 73.53 | 73.20 | 72.90 |
| Elvaloy (PG70-28) | 77.25 | 80.40 | 79.73 | 79.86 |
| SBS_L-G (PG70-28) | 75.65 | 75.87 | 76.22 | 76.14 |
| Novophalt (PG79-23) | 79.00 | 80.26 | 79.30 | 79.00 |
| Styrelf (PG87-27) | 87.00 | 87.83 | 87.29 | 87.05 |

## CONCLUDING REMARKS

The unification of fundamental rheological data for unmodified and polymer-modified asphalts provides a rather powerful tool to reduce subsequent experimentation and to ease the generation of rheological information in the future. It also provides the possibility of introducing new specification parameters that have the advantage of being easy to determine and at the same time being more flexible to changes, in case such a need for a specification change is felt in the future.

It has been shown that MVR can be very effectively used in determining the PG high temperature specification. The method relies on determining the temperature when $L^{1/n}$/MVR = 0.0245, based on the Superpave © binder specification requirement of |G*| / Sin* = 1 kPa for unaged asphalts at a frequency of 10 radians/s.

The FMD that is used for the generation of MVR data is a relatively simple, inexpensive piece of equipment and can be carried from place to place because of its relative lightweight. It neither needs any arrangements for air pressure nor requires a circulating water-bath to maintain a constant temperature environment. Since this equipment was originally built for taking polymer melt data at high temperatures (125EC - 300EC), it has an excellent temperature control system with variations of about 0.1EC, especially in the temperature range applicable to paving asphalts. It was found that MVR data generated from the FMD was very highly reproducible. In fact, in terms of repeatability of data, the FMD performs better than DSR. There are a number of other benefits in using the FMD as shown in Table 2. The evaluation of the benefits of the FMD are based on a number of factors such as initial equipment cost, operational cost, maintenance cost, operator training requirements, experimental ease, testing time, specimen size, variability of output, data reduction method, information obtained, and mobility or portability.

It is found that the FMD beats out DSR on most counts except specimen size and the information obtained. While from the DSR, all fundamental rheological parameters can be obtained, the FMD gives a single value measurement of MVR at a fixed load condition. However this single value can be correlated with each of the fundamental rheological parameters from the DSR. The unification technique thus upgrades the simple flow rate parameter to a level of high utility. The fact that the FMD is a relatively inexpensive equipment, operational costs are low, MVR data generation requires minimal training and the output has low level of variability, no calibration is needed, and the equipment is portable merits its use at the paving sites or at the refineries. The actual time for data generation is also very low. All this makes MVR an attractive parameter to be used for routine quality control as well as for new product development of asphalt binders, and would serve as an excellent "Purchase Guide" specification for the user / producer of paving asphalts.

## TABLE 2 - Comparison between DSR and FMD

| Considered Feature | DSR | | FMD |
|---|---|---|---|
| Initial Equipment Cost | $ 35000 | U | $5500* |
| Operational Cost | Power supply<br>Air pressure<br>Circulating water bath | U | Power supply only<br>No air pressure<br>No circulating water bath |
| Maintenance Cost | Complex Electronics<br>Very high repair cost<br>Expensive replacement parts | U | Simple Electronics<br>Little that can go wrong<br>At best, die may need replacement |
| ($60 each) | | | |
| | Need for maintenance contract | | No need for maintenance contract |
| Operator training | Complete day training is required in order to minimize errors during operation | U | Minimal or almost nil training is needed, thereby reducing the chances of error during operation |
| Experimental Ease | Not very easy to guess the strain levels to be used in a frequency sweep and hence extra data needs to be collected to make sure that obtained information is in the linear viscoelastic region | U | Not at all difficult to guess the load conditions in order to achieve MVR values between 1 and 50 to get most accurate data |
| | Replicate data has to be generated on a fresh sample for viscoelastic systems and needs an entire new run | U | Three MVR values are generated one after another for each sample loading. |
| Sample Preparation Time | U Heating the asphalt to 163EC and pouring in the silicone mold and cooling (about 5 minutes) | U | Heating the asphalt to 163EC and pouring into the barrel (about 5 minutes) |

* Melt Flow Indexer Model D4002 from Kayeness (Morgantown, PA)

## TABLE 2 (Continued) - Comparison between DSR and FMD

| Considered Feature | DSR | FMD |
| --- | --- | --- |
| Testing Time | Takes a long time to reach equilibrium temperature and the entire data generation takes over an hour without taking into account the time for establishing that the data is in linear viscoelastic range | U Equilibrates very quickly at all temperatures and the entire data generation takes only about 15 minutes (See Table 5 for details) |
| Specimen Size (For one set of data) | U 1 gm (For three sets of data) | 10 gms |
| Variability of Output (% STD / AVG) | 6 to 12 | U 0.2 to 2.0 |
| Data reduction method | Requires a computer and Windows '95 to run the software for calculation of various rheological functions | U Requires no computer as all calculations are done by the built-in software which does not require any other support |
| program either | | |
| Information Obtained | U Extensive information on the basic rheological properties of asphalts can be got in terms of \|G*\|, G@, G:, etc. | U Only a single value of MVR at a fixed load L condition can be got. But this value can be related to all fundamental rheological properties |
| generated from DSR | | |
| Mobility or Portability | Very heavy, Requires air pressure, Needs circulating water-bath and hence is not portable. | U Relatively light weight, Requires no air pressure, Needs no water-bath and thus is portable. |

## RELATED REFERENCES


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3. **Aroon Shenoy**, *Developing unified rheological curves for polymer-modified asphalts. Part I: Theoretical analysis*, Materials and Structures, Vol. 33(231), pp. 425-429 (2000); *Part II: Experimental verification*, Materials and Structures, Vol. 33(231), pp. 430-437 (2000).

4. **Aroon Shenoy**, *Estimating the unrecovered strain during a creep recovery test from the material's volumetric-flow rate (MVR)*, The International Journal of Pavement Engineering, Vol. 2( ), pp. (2002).

5. **Aroon Shenoy**, *High temperature performance grade specification of paving asphalt from the material's volumetric-flow rate*, Materials and Structures, Vol. 34( ), pp. (2001).

6. **Aroon Shenoy**, *Material's Volumetric-flow Rate (MVR) as a unification parameter in asphalt rheology and quality control / quality assurance tool for high temperature performance grading*, Applied Rheology, Vol. 10(6), pp. 288-306 (2000).