Statistical analysis on the test results was applied to the results of all the eight cutback samples using the different viscosity measuring instruments, by all the three formats discussed in chapter 2, and reported in Tables 4-B-2 and 4-B-3. Two samples of MC cutbacks MC-0 & MC-30, two samples of SC cutbacks of grades SC-250 from different manufacturers and one sample of each of the RC cutbacks of grades 70, 250, 800 and 3000, respectively, were selected for analysis. For each sample, eight observations were made by each instrument. Two computer programmes as shown in Appendix I were set up and run on IBM 1620 I model to obtain the standard deviation, difference from two sigma limit, coefficient of variation (for individual and pooled data) of observations on cutbacks and asphalt cements. It was noticed that:

(1) The repeatability of viscosity results on cutback asphalts by using Cannon-Fenske tubes, varied from 2 to 4 per cent of the mean according to format 1.
The D2S limit as per format 3 of repeatability was found to be zero per cent for seven samples, i.e. no difference exceeded $2\sqrt{2}\sigma$. For the sample SC-3, exceptionally, this value was found to be 7.14 per cent, which exceeded the 5 per cent limit.

(2) The repeatability for Zeitfuchs crossarm viscometers according to format 1 worked out close to 2 per cent with exception of one sample. Whereas for two samples the repeatability by D2S limit exceeded 5 per cent. This shows that the results on these two samples, should be considered suspect, contrary to the results of format 1.

(3) For vacuum capillary viscometers, the repeatability varied between 1 to 5 per cent, as per format 1. According to the format 3, one sample failed to fall within 5 per cent D2S limit.

(4) The standard deviation, in general, increased with the viscosity level.

(5) As per format 2, the repeatability for 95 per cent confidence limits from pooled data (56 degrees of freedom) was the lowest (3.43 per cent), for Zeitfuchs crossarm viscometers, and the highest (8.44
per cent) for Cannon-Fenske viscometers. For vacuum
capillary viscometers, it worked out to be 6.21 per cent.

(6) The statistical limits (upper and lower)
of mean viscosity for 95 per cent confidence limits from
pooled data worked out to be ± 0.74 per cent for Cannon-
Fenske viscometers, 0.55 per cent for vacuum capillary
viscometers and ± 0.30 per cent for Zeitfuchs crossarm
viscometers.

(7) The repeatability for shear rates with the
use of vacuum capillary viscometers according to format 1
varied between 2 to 6 per cent with only one exception of
9.93 per cent for one MC-0 sample. According to format 3,
two samples RC-800 and RC-3000, exceeded the D2S limit of
5 per cent. The coefficient of variation decreased in
general with increasing shear rates. As per format 1 and
format 2, the repeatability in general, for 95 per cent
confidence limits decreased with increasing shear rate
and varied from 11.59 per cent to 1.87 per cent. The
limits of the mean shear rate from pooled data, worked
out to be 1.08 per cent for 95 per cent confidence
level.

(8) It appears that a minimum number of
observations should be fixed before trying to obtain the repeatability by the difference two sigma limit concept (format 2), in order to compare its results with those of other formats. The results of repeatability according to format 2 appear to be quite satisfactory to report precision.

(9) The precision of Zeitfuchs crossarm viscometers was the highest compared to that of Cannon-Fenske and vacuum capillary viscometers, as suggested by two out of the three formats tried.

(10) The difference of mean viscosities estimated for a large population of data (Table 4-B-1) between various viscometers depends largely upon the standard deviation of each set of observations.

(11) It is hard to conclude how far the results of RC cutbacks were affected by vacuum. But, the repeatability with respect to mean was reported to be 4.76 and 4.15 per cent for RC-70 and RC-250 cutbacks by use of vacuum capillary viscometers. These values appear somewhat higher compared with that of other samples.

(12) It appears that for the two MG-0 and MC-30 samples, there was some difference in results of
repeatability. This is possibly due to other factors such as pre-heating method, handling and sampling.

(13) Shear rate measurements showed high overall repeatability of 12.34 per cent compared with 6.21 per cent for viscosity, from pooled data, for 95 per cent confidence limits.

B. DISCUSSION OF RESULTS - ASPHALT CEMENTS

B-1. VISCOSITY AT 39.2°F

The results of viscosity detailed in Table 4-A-7 and statistical analysis of Table 4-B-4 indicate that the repeatability of the sliding plate microviscometer is quite high, of the order of 20.82 per cent (44 degrees of freedom) for 95 per cent confidence limits for viscosity at 0.001 Sec.⁻¹. The average per cent repeatability of 18.54 per cent with respect to mean for the 22 samples tested also agrees reasonably with the above value. It is, however, important to note that the viscosities at both 0.01 and 0.001 Sec.⁻¹ shear rates were obtained by extrapolation from the graphs shown in Figures 4-A-1 to 4-A-22. It was first tried to run the graphic-recorder at 4 inches/hour speed, but it required very long intervals of time.
before appreciable movement could be registered on the chart. Besides, loads in excess of 10,000 grams were needed for shear rates up to 0.01 sec$^{-1}$, using glass plates. The plates suffered considerable chipping during the application of the heavy loads, thus affecting their durability and further use. Thus, it was obligatory to run the recorder at 40 inches/hour speed, which allowed measurements of viscosity between 0.002-0.006 sec$^{-1}$ shear rates for films of 300 micron thickness. Viscosity at 0.05 sec$^{-1}$ shear rate for all samples was extrapolated from the log shear stress - log shear rate lines (not shown). The slopes of log shear stress - shear rate curve varied for each of the three observations of every asphalt sample. All the samples, 85-100 and 120-150 penetration grades behaved as non-Newtonian materials at 39.2°F. The cause of high viscosity repeatability is also attributable to the deformations of the chain during the experiment, lack of very precise temperature control, use of glass plates and lack of controlled rate of loading during the testing programmes. However, it is interesting to note that the eleven 85-100 and ten 120-150 penetration grade asphalts showed mean viscosities between 500-700 and 170-390 megapoises respectively at 39.2°F with the
exception of one. The highest and lowest values of average shear susceptibility were -0.316 and -0.073, respectively. But most values were close to -0.20. The repeatability for the shear susceptibility is not a function of the degree of shear susceptibility, so that the precision is given as allowable spread between slopes and not as a per cent of mean (59). According to the statistical analysis, the slope difference for 95 per cent confidence limits worked out to be 0.1364 with 21 degree of freedom. The grand average slope difference worked out to be 0.1350, which agreed closely with the above value. It was difficult to obtain exactly 300 micron films of samples and hence a tolerance of ± 30 microns was noticed in spite of all the care taken while making the samples. The coefficient of variation for viscosity for pooled data (22 samples) worked out to be 7.3 per cent. The ± per cent variation of mean viscosity for 95 per cent confidence limits worked out between 19-26 per cent for most samples considered individually. A natural plot of shear stress versus shear rate is shown in Figure 4-A-23. Application of higher loads at the start, as suggested by ASTM D-4 Committee (60) was not found very convenient. Sometimes the plates were noticed to be slipping out from each other due to
brittleness of asphalt film, while loading with heavy weights first. Loading initially with higher weights would also affect the transient visco-elastic properties of the asphalt. The repeatability according to D2S limit format with three runs on each sample worked out 0.00 per cent in spite of the fact that the repeatability was very high using other formats stated above. This shows that a certain minimum number of test runs is necessary to make successful application of this new proposed format No.3.

Excessive agitation of the water bath also affects significantly the shear stress on plates, and make slight lateral displacement of the plates during the test. Excessive heating during preparation of sample also results in high viscosity values (61). Heating with an infra red lamp was preferred to hot plate heating.

B-2. VISCOSITY AT 77°F

The results of viscosity at 77°F are detailed in Tables 4-A-8 and 4-B-5 of 28 asphalt cements. Thirteen samples of 85-100 penetration, ten samples of 120-150 penetration, two samples of 200-300 penetration,
one each of 40-50, 60-70 and 70-85 penetration grades were used in the investigation from various sources and refineries in U.S.A. The 85-100 penetration samples showed a range of viscosity at 0.05 shear rate between 1.24-1.71 megapoises, the 120-150 penetration samples showed a range of 0.347 to 1.00 megapoises. The 200-300 penetration samples gave viscosity of 0.20 and 0.23 megapoises. This shows that for the samples tested the variation is not too wide in the range of viscosities. However, these are few samples used in the state of Wisconsin and the number is not too large to generalize the results. The microviscometer responded excellently at this temperature. As far as possible films of 100 ± 25 microns were tried for testing at 77°F. Film thickness appears to have some effect on magnitude of viscosity. Most samples responded very close to Newtonian materials; the degree of complex flow varied between 0.91 to 0.97 for all samples. The average per cent repeatability from 28 samples, with respect to mean (format 1) worked out as 5.1 per cent. Besides, from the pooled data it was observed that the per cent coefficient of variation is 3.07, the per cent repeatability for 95 per cent confidence
limits (with 56 degrees of freedom) is 8.07 per cent. The repeatability with three runs on each sample, by D2S limit format (No. 3) was 0.00 per cent. The statistical ± per cent variation of the mean viscosity for 95 per cent confidence limits for individual samples varied from 5-10 per cent in general. The logarithmic plots of shear stress versus shear rate are shown in Figures 4-B-1 to 4-B-28 for each of the three runs on all the twentyeight samples of asphalt cements. These plots are used to determine the viscosity at 0.05 Sec.\(^{-1}\) shear rate. The shear stress-shear rate plots on natural scale are shown for average viscosities of each of the 28 samples in Figure 4-B-29.

B-3. VISCOSITY AT 140°F

The viscosity of all 28 samples was measured by Cannon-Manning vacuum viscometers at vacuum of 30 cm. mercury. The procedure adopted was as outlined in ASTM standard D2171-63T, tentative method of test for absolute viscosity of asphalts (17). The results are detailed in Tables 4-A-9 and 4-B-5. The range of viscosity of thirteen 85-100 and ten 120-150 penetration samples from various sources varied between 960-2170 and 650-960 poises, respectively. Cannon
vacuum calibrated capillary viscometers, sizes 9, 10, 11 and 12 were used in the investigation. Only one viscometer in each size was available.

The description of apparatus used is detailed in chapter 3. The repeatability for viscosity and shear rates was determined with respect to the mean, the difference two-sigma limit and 95 per cent confidence limits for every sample individually as well as for pooled data. For 23 samples, two different sizes of viscometers were used for viscosity determination and for the other five samples, only one size was used. Eight observations of viscosity were made on each sample, giving a seven degree freedom for statistical analysis. The coefficient of variation for pooled data was found to be 0.965; for individual samples, it varied between 0.44-2.02 per cent. The repeatability of viscosity for pooled data was found to be as follows:

(Format 1) with respect to mean: 3.24 per cent (average of 28 samples)

(Format 2) for 95 per cent confidence limits: 2.67 per cent for 196 degrees of freedom.

The value of repeatability of individual
samples for the above two formats varied between 1.11-4.85 per cent (with exception of 6 per cent for one sample) and 1.20-5.11 per cent respectively. The repeatability according to the D2S limit (format 3) was noticed to be 3.57 per cent for 18 samples, 7.14 per cent for 2 samples and 0.00 per cent for 8 samples. Thus, 26 samples satisfied the criterion of 5 per cent difference two sigma limit and only two of them exceeded the 5 per cent limit. The point of contrast between the viscosity results of format 3 and the other two formats discussed above is of interest for some of the samples. Considering the results of Sample Nos. 8727, 7103, 9528 and 6006, it is noticed that their repeatability values are as follows:

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Format Number</th>
<th>% of mean</th>
<th>95% confidence limits</th>
<th>D2S limit</th>
<th>± Limits of mean %</th>
</tr>
</thead>
<tbody>
<tr>
<td>8727</td>
<td>1</td>
<td>3.35</td>
<td>4.61</td>
<td>0.00</td>
<td>1.15</td>
</tr>
<tr>
<td>7103</td>
<td>2</td>
<td>3.17</td>
<td>3.51</td>
<td>7.14</td>
<td>0.38</td>
</tr>
<tr>
<td>9528</td>
<td>3</td>
<td>3.12</td>
<td>3.27</td>
<td>7.14</td>
<td>0.32</td>
</tr>
<tr>
<td>6006</td>
<td>4</td>
<td>4.34</td>
<td>5.21</td>
<td>3.57</td>
<td>1.30</td>
</tr>
</tbody>
</table>

It may be observed that the samples 7103 and 9528 satisfy formats 1 and 2, but fail to satisfy format 3. Sample 8727 has 4.61 per cent repeatability...
as per format 2, but 0.00 per cent repeatability as per format 3. Sample 6006 has 5.21 per cent repeatability as per format 2, but 3.57 per cent repeatability as per format 3. Thus, it appears that more than eight test runs are necessary to obtain repeatability results of format 3 to be comparable with those of other formats. The results of formats 1 and 2 agree reasonably when compared with for individual as well as pooled data. Repeatability of 3 per cent for Cannon vacuum viscometers for measurement of viscosity at 140°F is possible to obtain for asphalt cements.

The reason for using two different sizes of viscometers was to conduct the test runs rapidly and to study whether any non-Newtonian behaviour was exhibited by the samples. But on checking few results, it was noticed that the asphalts behaved as Newtonian materials at this temperature.

B-4. SHEAR RATE AT 140°F

The repeatability of shear rate measurements varied with the two sizes of viscometers used for the same sample. The viscometer size 11 showed less value of repeatability compared with the one of size 12. For
85-100 and 120-150 penetration grades, viscometers with following constants were used:

<table>
<thead>
<tr>
<th>Viscometer size</th>
<th>Viscosity Constants</th>
<th>Shear Rate Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bulb C</td>
<td>Bulb D</td>
</tr>
<tr>
<td>11</td>
<td>6.10</td>
<td>1.934</td>
</tr>
<tr>
<td>12</td>
<td>21.25</td>
<td>7.620</td>
</tr>
</tbody>
</table>

From the pooled data on 23 samples, the value of coefficient of variation and repeatability worked out as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Viscometer size 11</th>
<th>Viscometer size 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average percentage of mean</td>
<td>2.44%</td>
<td>4.68%</td>
</tr>
<tr>
<td>95% Confidence limits (d.f. = 69)</td>
<td>3.26%</td>
<td>6.49%</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>1.17%</td>
<td>2.33%</td>
</tr>
</tbody>
</table>

Five samples, for which shear rate measurements were taken by only one size viscometer gave the following results (pooled):

<table>
<thead>
<tr>
<th>Format</th>
<th>Repeatability percentage of mean</th>
<th>Repeatability 95% Confidence limits (d.f. = 35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Format 1</td>
<td>3.99%</td>
<td>4.51%</td>
</tr>
<tr>
<td>Format 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thus, use of proper size of viscometer should result in almost the same value of repeatability for viscosity as well as shear rate. The value of repeatability for shear rate as per the D25 limit format was 0.00 per cent for 23 samples tested with two sizes of viscometers, but it was observed that for 2 out of the remaining 5 samples tested with one size viscometer, repeatability was 3.57 per cent.

It would also appear from the results of Table 4-A-9 that the use of two sizes of viscometers result in greater difference in shear rate measurements than in viscosity measurements. This is attributable to the values of constants specified for computing viscosity and shear rate values from flow periods. It is also clear that application of the D25 limit format for repeatability is more effective for a still larger number of observations or tests on each sample.

There are great chances of trapping air bubbles in measuring viscosity of asphalts at 140°F. This was noticed when starting the testing programme. Care is necessary in charging the viscometer tubes, so as to avoid entrapment of air bubbles.
B-5. VISCOSITY AT 275°F

The results of viscosity at 275°F are detailed in Tables 4-A-10 and 4-B-6. Cannon-Fenske Reverse Flow viscometers of sizes 350, 400 and 450 were used in the investigation. The calibration constants were extrapolated for 275°F as recommended by the Cannon Instrument Company. The results suggested that use of this viscometer is very favourable for viscosity testing at 275°F.

Eight observations of viscosity were made on each sample. The coefficient of variation for individual samples ranged between 0.41-1.84 per cent, and 1.147 for pooled data.

The repeatability results are as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Format 1</th>
<th>Format 2</th>
<th>Format 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>range</td>
<td>range 3.57%</td>
<td>3.57% on 10 samples</td>
</tr>
<tr>
<td>samples</td>
<td>1.21-3.83%</td>
<td>1.37-6.14%</td>
<td>1.37-6.14% on 17 samples</td>
</tr>
<tr>
<td>(d.f. = 7)</td>
<td></td>
<td>(d.f. = 17)</td>
<td></td>
</tr>
<tr>
<td>Pooled data</td>
<td>2.59%</td>
<td>2.77%</td>
<td>2.77% on 1 sample</td>
</tr>
<tr>
<td>(average)</td>
<td></td>
<td>(d.f. = 196)</td>
<td></td>
</tr>
</tbody>
</table>

Thus, a repeatability of 3 per cent is suggested for precision of results with this viscometer, for routine work. There was a difficulty of cleaning with a fear of cracking of the vacuum capillary viscometers, first tried in the investigation. It consumed too much time in cleaning these instruments. But
proper change in set up for cleaning viscometer tubes may help speed up the testing work. The use of vacuum capillary viscometer at 275°F facilitates viscosity measurements at high shear rates up to 3000 reciprocal seconds at vacuum of 30 cm. of mercury. An average value of coefficient of variation for viscosity was worked out from the results of each of 28 samples at various temperatures of testing. The values are found to be 9.7 per cent at 39.2°F, 2.65 per cent at 77°F, 0.97 per cent at 140°F and 0.99 per cent at 275°F.

B-6. PENETRATION-VISCOSITY CORRELATION

Figure 4-D-6 represents a natural plot of penetration at 77°F versus viscosity at 140°F. No indication of proper correlation appears from this plot. Other figures from 4-D-3 to 4-D-7 show logarithmic plots of penetration at 77°F (P) versus viscosities at 39.2°F, 77°F, 140°F and 275°F. A straight line curve was fitted in each of these plots by the method of least squares. The equations of these lines are as follows:

\[
\log \eta_{39.2} = 9.5 - 1.34 \log P
\]

\[
\log \eta_{77} = 8.6 - 1.86 \log P
\]
It appears that a good correlation exists between viscosity at 77°F and penetration at 77°F.

Figures 4-D-8 and 4-D-9 show the logarithmic plots of penetration at 60°F versus viscosities at 39.2°F, 77°F and 275°F respectively. The equation of the lines of regression for these plots are as follows:

\[
\log \eta_{39.2} = 3.12 - 1.57 \log P
\]
\[
\log \eta_{77} = 2.39 - 0.69 \log P
\]
\[
\log \eta_{275} = 2.36 - 0.37 \log P
\]

The correlation between viscosity at 140°F and penetration at 60°F is very feeble and hence not reported here.

**B-7. TEMPERATURE VISCOSITY PLOTS**

Figure 4-C-2 indicates the plot of log-log viscosity (poises) versus log absolute temperature for four typical asphalt cements. Figure 4-C-1 represents the viscosity-temperature lines for the same samples on specially ruled ASTM graph paper (Walther chart). The equation that describes these lines is the Walther equation, \( \log\log(\eta) = a + m \log T \). The height and
slope of this line adequately and simply describe much of what is known for specifying and using an asphalt.

The numerical value of the slope, m, which is equal to:

\[
\frac{\log_{140} \eta - \log_{275} \eta}{\log (140+460) - \log (275+460)}
\]

is shown in Table 4-B-9, as obtained from nomogram of Figure 4-C-3.

Varying degree of deviation from straight line occurred in the \( \eta - T \) relations below 140°F when data was plotted on the Walther charts. The compact form of the chart on the axis-log-log viscosity yielded inaccurate values of viscosity at 60°F. \( \eta_{60} \) at 0.05 Sec.\(^{-1}\) shear rate was interpolated from the viscosity temperature plots. In absence of experimentally determined values, no check could be made on the interpolated figures. Hence, no correlation could be obtained between \( \eta_{60} \) and \( P_{60} \).

B-8. POSSIBILITY OF VISCOSITY GRADING

Figure 4-D-5 and Table 4-B-10 show how the present 85-100 and 120-150 penetration grades would fit in the proposed viscosity grading at 140°F. It was
noticed that only four samples could be placed in AC-5 grade (500-750 poises). Eight samples of 120-150 penetration grade had viscosity range from 768-958 poises, thus suggesting to extend the upper limit of AC-5 grade to 1000 poises. Nine samples of 85-100 grade satisfied the AC-10 grade limits (1000-1500 poises) and four samples exceeded the upper limit of 1500 poises.

Alternatively, the Asphalt Institute currently proposed alternative research specifications (Table 1-2) involving grades AC-3 (225-375 poises), AC-6 (450-750 poises), AC-12 (900-1500 poises), AC-24 (1800-3000 poises), and AC-48 (3600-6000 poises). According to this proposal, four samples could be placed in AC-6 grade and three exceeded the upper limit of AC-6. Thirteen samples satisfied the AC-12 grade limits and this included four 120-150 penetration grade asphalts and nine 85-100 penetration grade asphalts. Four 85-100 samples exceeded the upper limit of AC-12 grade.

C. CONCLUSIONS AND RECOMMENDATIONS

Based upon the materials, methods of testing and instruments used in this investigation, the following conclusions and recommendations are stated:
(1) The viscosity at shear rate of 0.001 Sec.\(^{-1}\) and shear susceptibility measurements with glass plates using sliding plate microviscometer at 39.2°F resulted in high repeatability, due to lack of precise temperature control and uncontrolled rate of loading. Use of steel plates is highly desirable. Cone plate viscometer, dilatometric or penetrometric techniques of measuring glass transition temperature are more accurate for low temperature work. Rheogoniometer, a refinement of a design by Weissenberg is the most elegant research instrument.

(2) The viscosity measurements at 77°F showed that there is a certain range of viscosity at 0.05 Sec.\(^{-1}\) shear rate for each group of penetration grade asphalt cements tested during the investigation. The repeatability for viscosity measurement of the instrument is 5 per cent (of the mean) at this temperature and 8.07 per cent at 95 per cent confidence limits for pooled data. However, ASTM Committee D-4 on road and paving materials, recommends to report viscosity at 0.001 reciprocal seconds at 39.2°F with steel plates, whereas Bureau of Public Roads suggests to report the same at 0.05 Sec.\(^{-1}\). In the opinion of the author,
viscosity at 39.2°F should be reported at the same shear rate viz. 0.05 Sec.⁻¹ for the purposes of proper comparison and interpretations.

(3) Repeatability of 3 per cent by calibrated Cannon vacuum viscometers can be obtained for penetration grade asphalts, at 140°F for viscosity as well as shear rate measurements. Previous investigators, however, reported a repeatability of 5 per cent of the mean. Limits of mean of individual samples ranged from 0.3-1.28 per cent.

(4) The application of difference two sigma limit format of repeatability is more effective for large number of observations or tests on each sample at the test temperatures. There is yet a good agreement between results of viscosity repeatability with respect to mean, 95 per cent confidence limits and D2S limits at 140°F.

(5) Use of a vacuum capillary viscometer with higher value of bulb constants of viscosity results in increasing value of repeatability for shear rate measurements. Since most of the asphalts received from the manufacturers were Newtonian at 140°F, the difference in values of shear rate repeatability is not very
significant.

(6) A repeatability of 3 per cent (for pooled data) for routine testing may be suitable for Cannon-Fenske viscometers (reverse flow type) for rapid viscosity measurement of asphalts at 275°F.

(7) The coefficient of variation of viscosity is found to be 9.7 per cent at 39.2°F, 2.65 per cent at 77°F, 0.97 per cent at 140°F and 0.99 per cent at 275°F.

(8) The proposed limits of AC-12 grade at 140°F were satisfied by a few 120-150 penetration grade and most of the 85-100 penetration grade samples tested.

(9) The value of viscosity-temperature slope for the asphalt samples tested ranged from -3.39 to -3.59 for 85-100 penetration samples, and -3.45 to -3.61 for 120-150 penetration samples as obtained from the nomogram of Figure 4-C-3. This is true between temperatures of 140°F and 275°F. For lower temperatures, the slopes are different.

(10) The viscosity variation at 39.2°F for ten 85-100 and ten 120-150 penetration grades ranged between 412-692 and 172-387 megapoises respectively. The range of variation at 77°F was in general noted to be 1.0-2.0
megapoises for thirteen 85-100 penetration samples and 0.5-10 megapoises for ten 120-150 penetration samples. At 140°F this range was observed to be 950-2150 poises and 650-950 poises respectively. But it is felt that this is a small number of samples to generalize the results.

(11) There seems to be a strong correlation between penetration at 77°F and viscosity at the same temperature for asphalts cements from various refineries.

It is necessary to visualize that the asphalt in the pavement is subject to a broad spectrum of stress conditions like settlement, light or heavy static loads, and fast and slow moving traffic. These correspond to different rates of shear varying from $10^{-7}$ to $10^{3}$ Sec.$^{-1}$. It is thus necessary to have the knowledge of the behaviour of asphalt at these various shear rates to predict its exact behaviour in the pavement.

Absolute rate theory might be very useful in explaining the rheological behaviour of the asphalt cements. Research workers have shown that within a specified temperature range the absolute rate theory is applicable to asphalts regardless of their physical
Oscillatory visco-elastometers, instruments based on sudden or fixed rate loading or deformation, and the Instron tensile tester are perhaps more suitable for further research on visco-elastic behaviour of asphalts. The Instron unit is a versatile and precise instrument for measuring tensile or compressive stresses and for applying deformation in extension or compression to a test sample.