OBJECTIVES

To examine the consistency of a sample of bitumen by determining the distance in tenths of a millimetre that a standard needle vertically penetrates the bitumen specimen under known conditions of loading, time and temperature.

BACKGROUND

This is the most widely used method of measuring the consistency of a bituminous material at a given temperature. It is a means of classification rather than a measure of quality. (The engineering term consistency is an empirical measure of the resistance offered by a fluid to continuous deformation when it is subjected to shearing stress). The consistency is a function of the chemical constituents of a bitumen, viz. the relative proportions of asphaltenes (high molecular weight, responsible for strength and stiffness), resins (responsible for adhesion and ductility) and oils (low molecular weight, responsible for viscosity and fluidity). The type and amount of these constituents are determined by the source petroleum and the method of processing at the refinery.

Penetration is related to viscosity and empirical relationships have been developed for Newtonian materials. If penetration is measured over a range of temperatures, the temperature susceptibility of the bitumen can be established. The consistency of bitumen may be related to temperature changes by the expression

\[ \log P = AT + K \]  

where
- \( P \) = penetration at temperature \( T \)
- \( A \) = temperature susceptibility (or temperature sensitivity)
- \( K \) = constant

A Penetration Index (PI) has been defined for which the temperature susceptibility would assume a value of zero for road bitumens, as given by

\[ \text{PI} = \frac{20(1 - 25A)}{(1 + 50A)} \]
The value of $A$ (and PI) can be derived from penetration measurements at two temperatures, $T_1$ and $T_2$, using the equation

$$A = \log \text{(pen at } T_1) - \log \text{(pen at } T_2) \over T_1 - T_2 \quad \ldots \quad (3a)$$

Research has shown that, for conventional paving grade bitumens, the Ring-and-Ball Softening Point temperature is the same as that which would give a penetration of 800 d-mm. This, together with the penetration at 25 °C, can be used to compute $A$ where

$$A = \log \text{(pen at } 25 \, ^\circ\text{C}) - \log 800 \over 25 - \text{ASTM softening point} \quad \ldots \quad (3b)$$

The nomograph as given in Figure 1 enables the PI to be deduced approximately from the penetration at 25 °C and the softening point temperature. Typical values of PI are

<table>
<thead>
<tr>
<th>Bitumen type</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blown Bitumen</td>
<td>&gt;2</td>
</tr>
<tr>
<td>Conventional Paving Bitumen</td>
<td>-2 to +2</td>
</tr>
<tr>
<td>Temperature Susceptible Bitumen (Tars)</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

PI values can be used to determine the stiffness (modulus) of a bitumen at any temperature and loading time. It can also, to a limited extent, be used to identify a particular type of bituminous material. One drawback of the PI system is that it uses the change in bitumen properties over a relatively small range of temperatures to characterise bitumen; extrapolations to extremes of the behaviour can sometimes be misleading.

**SUMMARY OF TEST METHOD (ASTM 1988)**

The sample is melted and cooled under controlled conditions. The penetration is measured with a penetrometer by means of which a standard needle is applied to the bitumen specimen under specific conditions.
Figure 1. Nomograph for the Penetration Index of bitumen (Whiteoak, 1990)

Draw a line between the softening point (line 'A') and penetration (line 'B') values. The intercept on line 'C' is the PI of the bitumen.
PROCEDURE

The penetration apparatus (Figure 2) is specified in many standards throughout the world but has always the same basic requirements as ASTM D5.

1. Specimens are prepared in sample containers exactly as specified (ASTM D5-97) and placed in a water bath at the prescribed temperature of test for 1 to 1.5 hours before the test.

2. For normal tests the precisely dimensioned needle, loaded to 100 ± 0.05 g, is brought to the surface of the specimen at right angles, allowed to penetrate the bitumen for 5 ± 0.1 s, while the temperature of the specimen is maintained at 25 ± 0.1 °C. The penetration is measured in tenths of a millimetre (decimillimetre, d-mm).

3. Make at least three determinations on the specimen. A clean needle is used for each determination. In making repeat determinations, start each with the tip of the needle at least 10 mm from the side of the container and at least 10 mm apart.

Figure 2. Apparatus for the bitumen penetration test
RESULTS

The results are very sensitive to test conditions and bitumen specimen preparation and the requirements of the appropriate standard must be rigidly adhered to. The maximum difference between highest and lowest readings shall be:

<table>
<thead>
<tr>
<th>Penetration (d-mm)</th>
<th>0-49</th>
<th>50 - 149</th>
<th>150 - 249</th>
<th>250-500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Difference</td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>20</td>
</tr>
</tbody>
</table>

DISCUSSION

(a) Report the source and type of bitumen.

(b) Specify the conditions of the test (temperature, load, time). Note the three separate readings and quote the penetration as the average to the nearest whole unit.

(c) Comment on the difference between the highest and lowest readings and, if sub-standard, offer an explanation.

(d) Compare the average penetration with the manufacturer's quoted range and, if outside this, offer an explanation.

(e) Calculate the PI and comment on the value obtained. (Make sure the penetration and softening point values are obtained from the same batch of bitumen).

(f) Compile and compare results with other groups.

REFERENCES
