RHEOLOGICAL PROPERTIES OF BITUMINOUS ROOFING MATERIALS AT VARIOUS TEMPERATURES

XU ZHAO-DONG

Wuhan Institute of Building Materials
Wuhan, People's Republic of China

Bituminous materials used for roofing are non-crystalline state thermal-plastic substances, that change in consistency gradually with changing temperature. However, they do not have a sharply defined melting point. Thus the transition state can be described by a series of temperatures describing condition state, which may be called the temperature state point. Temperature state points in frequent use are brittle point, softening point, penetration, fusing point, flash point and burning point.

Each state point distinguishes different states such as elastic, elastic-plastic, plastic, plastic-yielding, liquid or critical boiling state. Brittle point, hardening point, softening point and fusing point indicate bitumen temperature under certain condition states, while penetration denotes bitumen viscosity under fixed temperature conditions.

The major indexes each nation applies to distinguish bitumen properties are softening point and penetration. The GB standard in China does it this way, as ASTM standards do in the United States. However, through the further study of indexes such as softening point and penetration, many experts believe that it is unrealistic to grade the standards of roofing bitumens using softening and penetration as basic criteria. For instance, V.P. Puziauskas has done much work to show there is little relationship between softening point and viscosity. The viscosity for certain bitumens graded by softening point alone could vary significantly. For example, in the U.S., two asphalts of the same type measured at 71.1C, can change in viscosity as much as 17 times (from 120,000 poises to 2,000,000 poises). Some nations are working toward grading roofing bitumens by viscosity, which has certain advantages. Nevertheless, as roofing bitumens are studied by means of rheology it has been found that, within the range of performance temperatures, bitumens are not simply viscoelastic material. Therefore, their important properties cannot be demonstrated by viscosity alone.

This paper gives the results of research on the rheologic properties of number 10 asphalt in China. Viscoelastic property index J is suggested to describe bitumen states, and taking this as the basis to grade bitumen standards, bitumen properties can be demonstrated more accurately.[2]

RHEOLOGICAL BEHAVIOR OF BITUMENS UNDER DIFFERENT TEMPERATURE CONDITIONS

Chinese number 10 standard asphalt (similar to American ASTM D312 IV type asphalt) is described in this paper. Its indexes are:

- Softening point: 112C
- Penetration: 15.2 (25C, 100 grams, 1/10 millimeter)
- Elongation: 2.65 (25C cm)

Using a sheet shear rheometer, the creep process of Chinese number 10 asphalt is measured under different temperature conditions from 60C to 180C. The loading range selected was from 81.67 to 5444.44 dynes per square centimeter. The time cycle ranged from 0.1 to 10 seconds. The rheologic model setting up the special program library RHELIB was used to establish the rheologic model of number 10 asphalt under different temperatures.

Typical creep curves under different temperatures are shown in Figure 1.

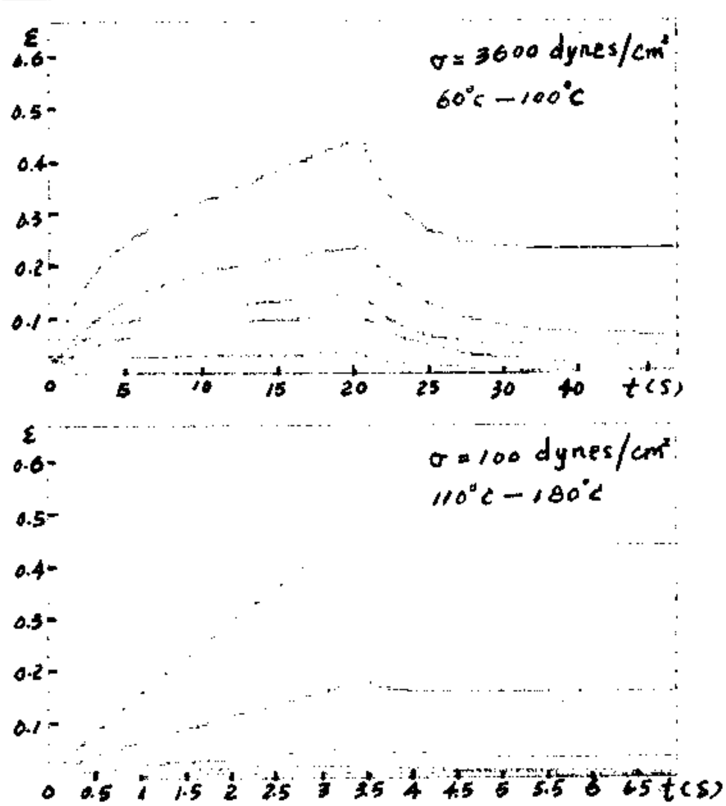

Figure 1

After selecting the best with the RHELIB program library, Chinese number 10 asphalt can be described by the Burgers Model. Its model structure is shown in Figure 2.

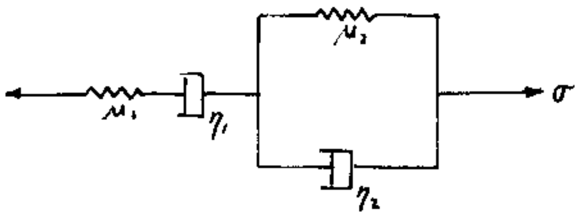

Figure 2

Where μ_1 is Elastic Modulus of Hooke Body.

η_1 is Viscosity of Newton Body.

μ_2 is Elastic Modulus of Hooke Element in Kelvin Body

η_2 is Viscosity of Newton Element in Kelvin Body.

The constitutive equation for the Burgers Model is:

$$\frac{\eta_2}{\mu_1}\frac{d^2\sigma}{dt^2}+(1+\frac{\mu_2}{\mu_1}-\frac{\eta_2}{\eta_1})\frac{d\sigma}{dt}+\frac{\mu_2}{\eta_1}\sigma=\eta_2\frac{d^2\varepsilon}{dt^2}+\mu_2\frac{d\varepsilon}{dt} \quad (1)$$

The rheologic parameters under different temperature conditions as given the RHELIB program library are shown in Table 1.

T	P1	P2	P3	P4
60 °C	376785	55600000	134935	666913
70 °C	466667	4520833	39474	184841
80 °C	417406	1430000	36388	103273
90 °C	490000	999603	20504	89057
100 °C	544444	295792	16144	38807
110 °C	544444	224552	11162	34310
120 °C	127035	41011	7504	7026
140 °C	260436	9400	5542	5186
160 °C	70250	1988	4784	1358
180 °C	23930	726	2389	1971

Table 1

Here $P1=\mu_1$, $P2=\eta_1$, $P3=\mu_2$, $P4=\eta_2$.

VISCOSITY AND ELASTICITY OF BITUMEN UNDER DIFFERENT TEMPERATURES

Since number 10 asphalt is a typical Burgers Body it has apparent viscosity, elasticity and retarded elasticity, and these properties also change with changing temperatures.

In Table 1, parameter P2 is the viscosity η of the viscous element in series. P2 describes bitumen viscosity. Its law of changing with temperature is shown in Figure 3.

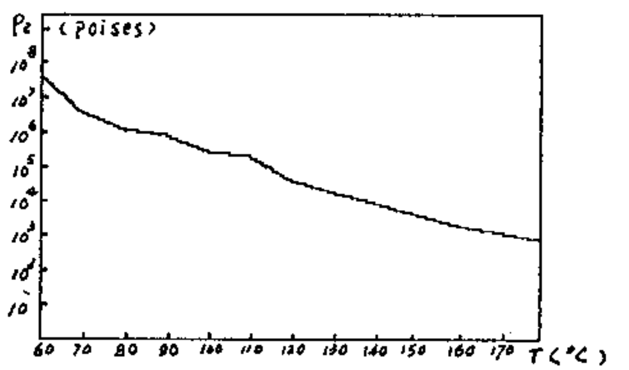

Figure 3

P1 is the elastic modulus of the elastic element in series of the Burgers model, which describes the instantaneous elastic deformation of the bitumen. P3 and P4 are parameters for the Kelvin body in the Burgers Model which describe retarded elastic deformation of the bitumen. In discussing the impact of temperature on bitumen, instantaneous and retarded elasticity should both be included for consideration. We define

$$E = P1*P3/(P1+P3)$$

as synthetic elastic modulus in the Burgers Model, and study the relationship between temperature and E. After taking the Kelvin body as an approximation of Hooke Body, E actually is the modulus of elastic elements P1 and P3 in series.

The E value for Chinese number 10 asphalt under different temperatures is given in Table 2.

T	60C	70C	80C	90C	100C
E	99354	36395	33470	19680	15679
T	110C	120C	140C	160C	180C
E	10937	7085	5426	4478	2172

Table 2

The law of E changing with temperature is illustrated in Figure 4.

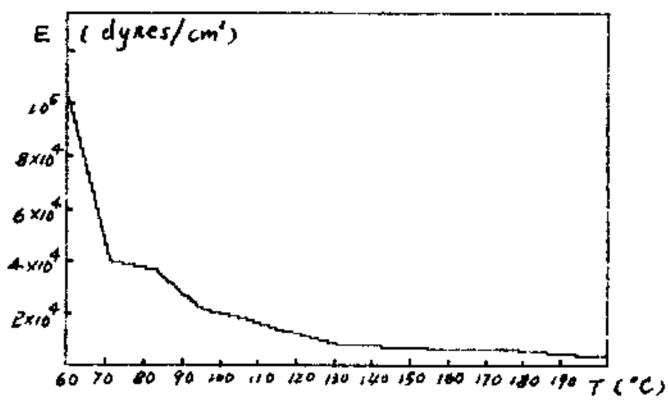

Figure 4

INDEX J FOR VISCOELASTIC PROPERTIES OF BITUMEN

As described in Section 2, it is evident that changes occur in bitumen viscosity and elasticity with changing temperature. Therefore, it appears to be advantageous to grade roofing bitumens by viscosity. However, limitations still are present because in grading by viscosity alone, the influence of elasticity within the range of performance temperatures has not been considered.

The author believes that using index J for viscoelastic properties, which is suggested in the reference literature[2], could overcome this one-sidedness.

As for the Burgers body, the formula for viscoelastic property index J is:

$$J=20\cdot Lg\frac{12\cdot 5/\eta_2}{(\frac{5}{\mu_1}+\frac{4}{\mu_2})/(\eta_2/\mu_2)} \quad (2)$$

J is the function for all rheological parameters. It considers all viscoelastic properties of bitumen. The alteration of any rheological parameter can cause a change in J value.

When $-\infty<J<0$, material emphasizes elasticity as its main property; when $0<J<+\infty$, material emphasizes viscosity as its main property. The greater J is, the more apparent is the liquid attribute of bitumen. The J value for Chinese number 10 asphalt under different temperatures is given in Table 3.

T	60C	70C	80C	90C	100C
J	−73.07	−43.16	−34.24	−26.59	−18.56
T	110C	120C	140C	160C	180C
J	−15.29	−13.92	10.36	13.5	40.4

Table 3

The law of J value changing with temperature is shown in Figure 5.

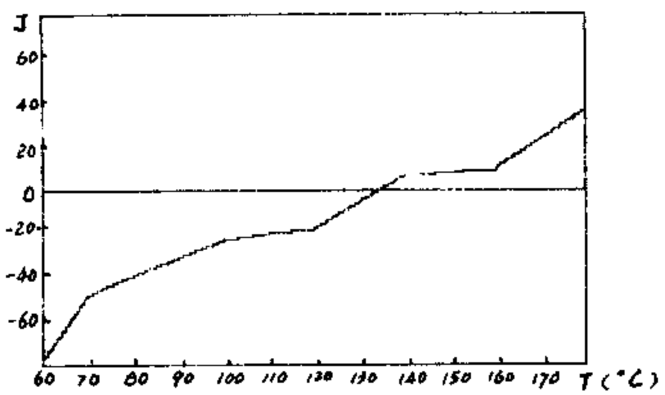

Figure 5

THE SIGNIFICANCE OF VISCOELASTIC PROPERTY INDEX J IN BITUMEN GRADING

As stated above, penetration and softening point traditionally have been used to grade bitumen. This does not provide ideal information for the consistency of roofing bitumen either at application temperatures or at performance temperatures.[1] However, limitations still exist in grading bitumen by viscosity alone. Therefore, a procedure for using J value under given temperature conditions as a grading standard for roofing bitumen is proposed in this paper. For example, the J value range under two temperature conditions such as application and performance temperatures could be prescribed, and these two J values could be used for bitumen grading. The J value provides more comprehensive information about bitumen viscoelastic properties for the range of application and performance temperatures.

The author made a concrete analysis of the relation J and each rheologic parameter in equation (2). After the logarithm sien, the numerator only relates to η_1 which denotes viscosity of material. In the denominator, the weight for $1/\mu_1$ is five but the weight for $1/\mu_2$ is only four. This indicates that instantaneous elasticity has greater impact on elastic attributes of material than does retarded elasticity. η_2/μ_2 is the delay time for retarded elasticity. The larger η_2/μ_2 is, the more apparent is the viscosity attribute.The smaller η_2/μ_2 is, the more apparent is the elastic attribute. It is clear that J is an overall description of the viscoelastic property of material. The viscosity is related to parameter η in Burgers Model. Synthetic modulus of elasticity E is only related to μ_1 and μ_2. They all are merely approximate descriptions of one specific aspect of material. Only J comprehensively summarizes the viscoelastic property of material and is suitable for use as a basic standard for bitumen grading.

DESCRIBING BITUMEN STATE WITH VISCOELASTIC PROPERTY INDEX J

As was discussed initially, traditional test methods measure different states by temperature state points such as brittle point, penetration, softening point, flash point and burning point. The testing methods for temperature state point vary considerably and are not necessarily related to such rheological properties as viscosity. Thus they are not ideal methods for distinguishing bitumen state.

This paper suggests using viscoelastic property index J to distinguish different bitumen states. The method involves prescribing J values for each bitumen state change, measuring the temperature when the bitumen reaches each prescriptive J value, and defining the state of some bitumen within certain temperatures ranges.

This method offers three advantages. First, measuring techniques and calculating methods for temperature state points are available. Second, J value directly relates to viscoelastic properties of materials and can be used as a rational basis for distinguishing between each state. Third, testing time is short and the method is convenient for widespread application.

SUMMARY

Taking Chinese number 10 asphalt as an example, this paper has studied rheological behavior of this bitumen at different temperatures. Further, it has suggested applying viscoelastic property index J as a basis for bitumen grading, since J distinguishes different bitumen state conditions and seems to be a rational method.

REFERENCES

[1] V.P. Puzinauskas, Specifications for Roofing and Industrial Asphalts, Proceedings of the Seventh Conference on Roofing Technology, April 14-15, 1983.

[2] The Single Parameter Index of Viscoelastic Property.

[3] Xu Zhao Dong and Chen De Kun, Research into Aperture Parameters of the Point Bonded Waterproof Layer, Materials and Structures Journal, Rilem, Paris, France. Fall 1984.

[4] Xu Zhao Dong and Chen De Kun, A Study on the Crack Resistance of Waterproof Coating, Second International Symposium on Roofs and Roofing, Brighton, U.K. September 21-24, 1981.