On the dynamic property of gumphalt

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Abstract

Viscoelastic nature of asphalt mixture depends on testing method, (creep, rate of strain and dynamic), and binder property. Generally, it is said that gumphalt mixture have more elastic nature than straight asphalt mixture, and it's nature is recognized by static test.

But it have never known that dynamic test is also useful one about testing the stress relaxation of gumphalt. So, dynamic test of gumphalt mixture was performed to exhibit it's nature and fatigue property in this paper. It is possible to divide deformation of asphalt mixture between elastic deformation and viscous flow, and former is usually called — solid and latter is also called — liquid. In static test (or long loading time), deformation of asphalt mixture looks like viscous flow, and in dynamic test (or short loading time), it's deformation nearly equal to elastic deformation.

But, these tendency depends on binder property, proportion of asphalt mixture and temperature too. In previous report[1], author examined dynamic property in straight asphalt, and explained it's fatigue property and viscoelastic nature. In this paper, dynamic test of gumphalt mixture is performed and then, viscoelastic nature, fatigue property and dependency of temperature are compared with straight asphalt mixture.

Many investigators[2)~5)] are interested in dynamic property of asphalt mixture, but few of them have ever adopted square wave. In dynamic test by square wave, it is difficult to analyze theoretically.

Introduction

There are many viscoelastic model due to asphalt mixture, but we cannot find out most suitable viscoelastic model which represent the property of deformation exactly. Namely, if asphalt mixture deform such as elastic deformation, Kelvin model or three parameter model with one viscous and two elastic elements will be used as it's viscoelastic model. And, if asphalt mixture flow such as viscous flow, Maxwell model or Burgers body will be adopted. So, it cannot be decide what model must be adopted.

These property of deformation will be change the shape by it's testing method and binder property. Rheology is therefore ordinary regarded as applying especially to the more complicated types of deformation and flow behavior that do not follow the simple laws of elasticity theory and hydrodynamics. This still includes a wide variety of systems, since ideal solids and liquids are only simple approximate idealizations of certain classes of real materials. It is said that the destruction of asphalt mixture is influenced by the characteristic of stress relaxation. In previous report, the characteristic of stress relaxation was explained by using of the rate of strain test and creep

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test.

But, it is not able to connect destruction of asphalt with stress relaxation. In this respect, it can be said that a mount of stress relaxation gradually decrease with the approach of destruction. Phenomenon of stress relaxation in dynamic test is excellently complained by adoption of square wave. And this stress relaxation property of straight asphalt will be different from gumphalt. So, gumphalt is used as binder in this report. In studying dynamic properties, a stress which varies sinusoidally with time is imposed, and the resulting strain, which also varies sinusoidally but in general is out of phase with the stress, is measured as a function of frequency. Dynamic measurements are obviously most appropriate for the short end of time scall. The use of square wave strain-time pulse has also been discussed by the reason of above mention. This is equivalent to a repeatedly reversing stress relaxation experiment. So, in this experiment, constant rate of strain and dynamic tests were practiced under constant temperature, and viscoelastic constant was calculated by the result of constant rate of strain test. Furthermore, fatigue property was compared straight asphalt mixture with gumphalt.

Experimental method and apparatus

Binder property is illustrated in Table 1. The proportion of asphalt mixture is decided by Talbot's equation which gives the maximum Marshall stability, maximum density and the particle size accumuration curve is controled by the equation of $P=100\ (d/D)^n$.

Table 1. Binder property.

Property \ Binder	Straight asphalt	Gumphalt
Grade	80–100	60–80
Penetration (25°C, 100 g 5 sec)	89	69
Softening Point R & B (°C)	42	52
Penetration index	0.17	+0.1

In upper equation, $D=10$ mm, $n=0.25$ and binder content is 8%. Size of specimen is $4.0\times4.0\times40$ cm, and the four point bending in a span length of 30 cm was employed. In order to make this size of specimen, we at first made slab type asphalt concrete which size is $20\times40\times6$ cm by compressing at 66 kg/cm^2 or 40 kg/cm^2 respectively, and the specimen is cut into that size by cutting machine. A stress-strain relationship and stress-time relationship were investigated at various temperatures by means of a beam flexure test, and the relaxation modulus by the constant rate of strain test was computed and a relaxation mastercurve was obtained. A dynamic electro-hydraulic machine was developed to investigate the dynamic response of mixtures and to determine the fatigue property. This dynamic machine was designed to give a various kinds of stress or strain wave and to measure the resulting strain or stress wave. Sinusoidal, square, triangle and tooth waveforms were obtained from a function generator and this equipment are controlled by a closed loop feed back system. A ramp function also enables measurement of creep and stress relaxation test. A symmetrical two point loading system of the repeated loading apparatus applies unidirectional loading flexural stresses to the simply supported $4 \times 4 \times 35$ cm beam specimen. The capacity of loading is plus and minus 200 kg and the maximum deflection of 5 mm was given. A visigraph enables continuous or intermittent recording of the input waveform, the actual load or deflection waveform in the specimen and the resulting deflection or load. Loading unit of these testing apparatus is shown at Fig. 1.

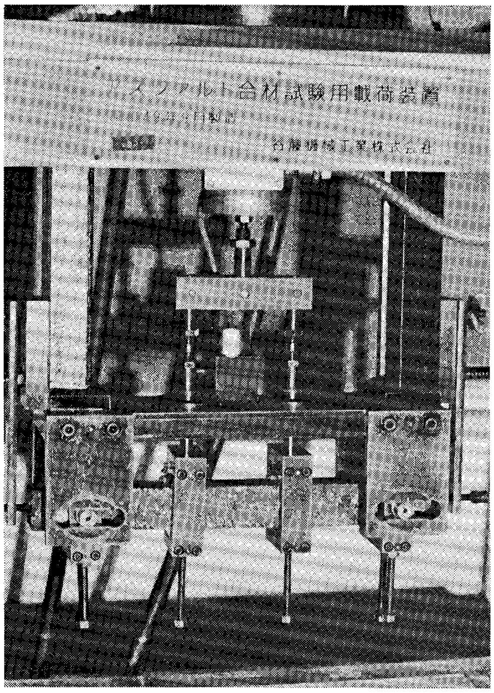

Fig. 1 Loading unit of dynamic electro-hydraulic machine.

Experimental results

The results of constant rate of strain test is illustrated in Fig. 2. Fig. 2–a represents stress-time relationship of gumphalt mixture at the rate of strain being 2×10^{-5} and temperature is -2°C, 6°C, 14°C. Fig. 2–b, represents stress-time relationship of straight asphalt mixture under the same conditions. In these figures, stress of gumphalt at the temperature being 14°C decrease after the time of 160 sec, and it indicate destruction of gumphalt mixture at that point. From these figure, it can be easily found that the tangent of stress-time curves gradually decrease with increasing temperature, but this tendency of gumphalt mixture is smaller than that of straight asphalt. Stiffness[2)] of this experiment is represented in Fig. 3. Fig. 3 is the stiffness of gumphalt mixture and straight asphalt. Stiffness also decrease with increase of loading

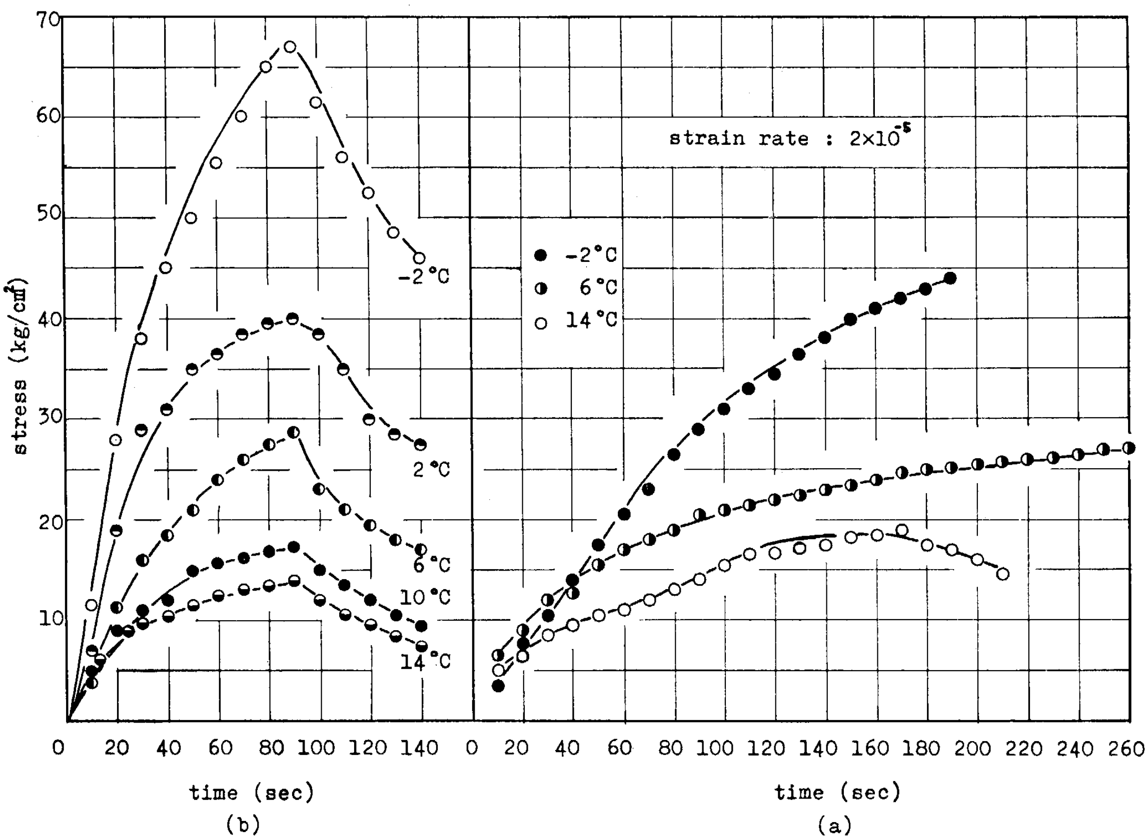

Fig. 2 The result of stress relaxation test.

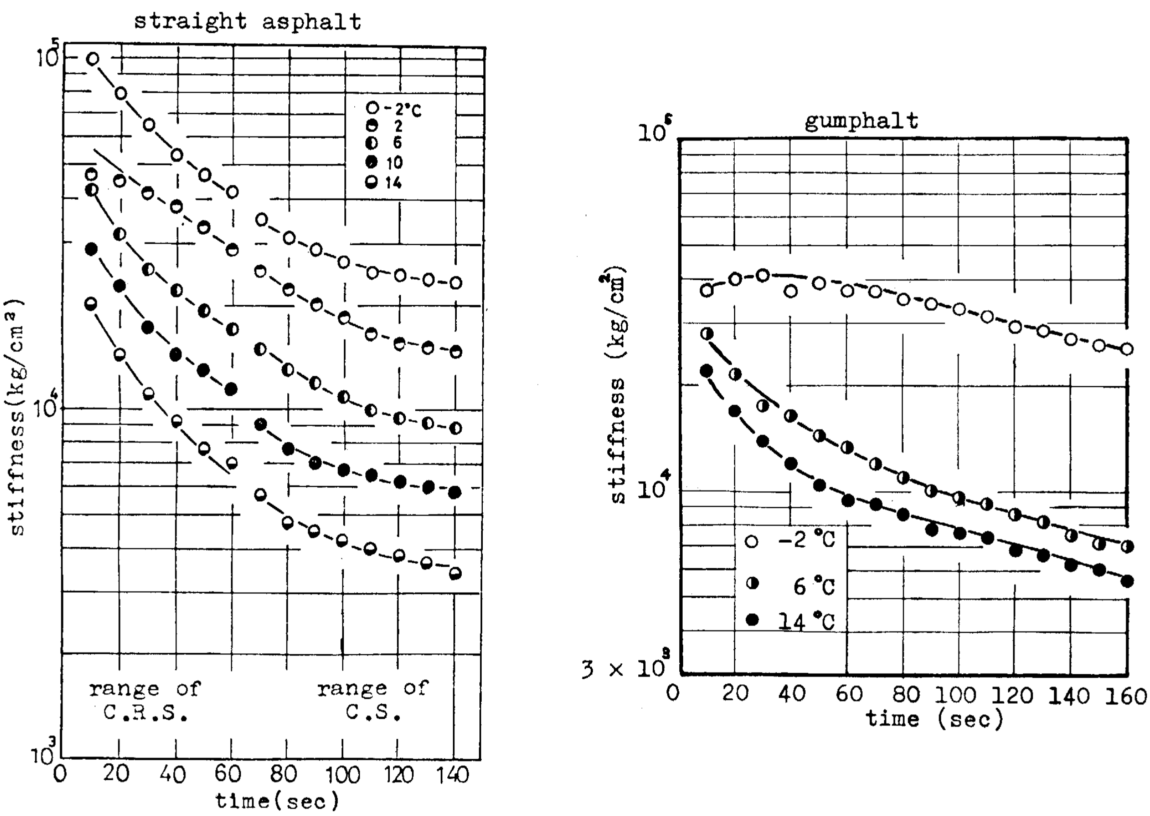

Fig. 3 Decrease of stiffness in different types of asphalt.

time, and it's tendency of gumphalt is slightly different from that of straight asphalt. Viscoelastic constants were computed by using of viscoelastic equation under the condition of constant strain rate. And it's result is

Spring constant of pure elastic element	: $1\sim2\times10^4$ kg·cm^{-2}
Spring constant of Kelvin model	: $1\sim8\times10^3$ kg·cm^{-2}
Viscous constant of Kelvin model	: $1\sim3\times10^6$ kg·sec·cm^{-2}

Upper limit of these constants is the value of temperature being -2°C and lower limit of constants is the value of 14°C. Viscous constant of Kelvin model is larger than that of straight asphalt. This fact is based on the elastic nature of gumphalt. The results of dynamic test is shown in Fig. 4 and Fig. 5. These figures represent relationship between strain and the number of cycles to failure in every temperature range and two types of wave form. The definition of destruction is the same as previous report. And all of measured value lie on the straight line, whose equation can be decided by using the Principle of Least Squares. Equations of straight line at every temperature and types of wave form are given by

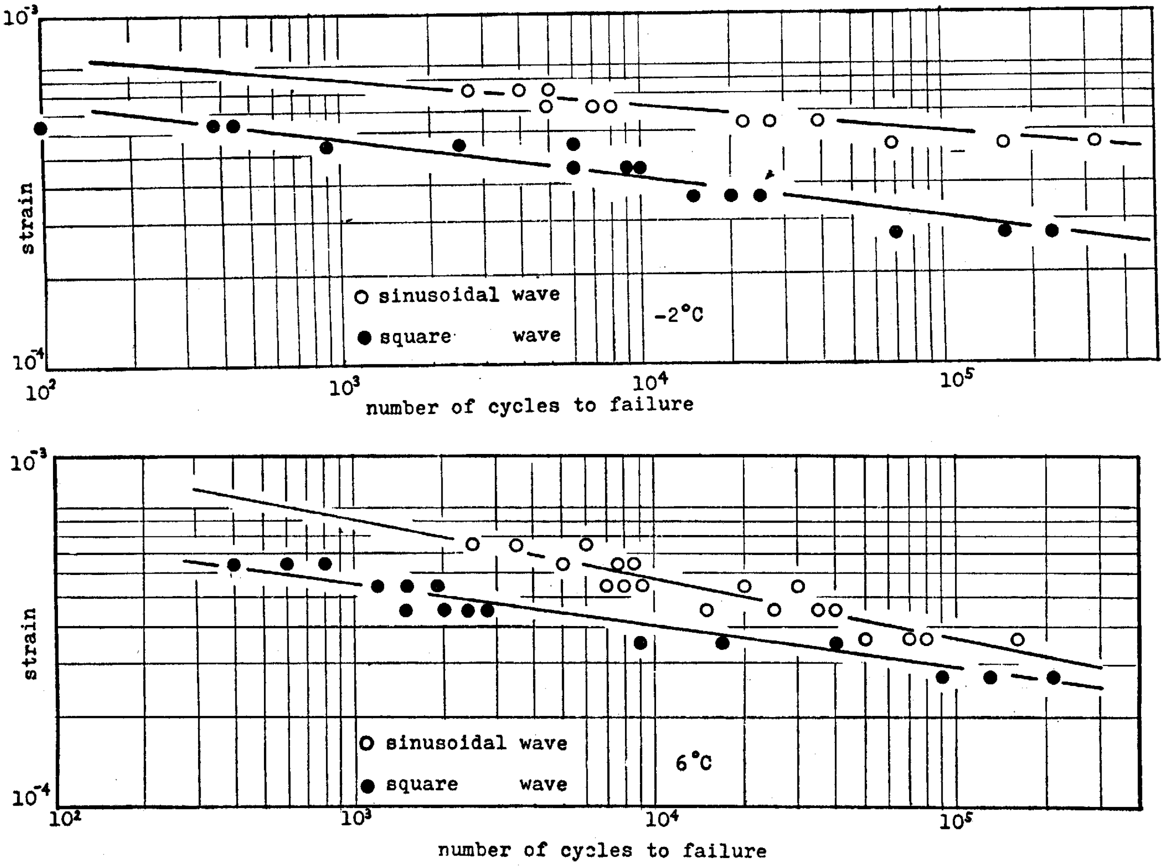

Fig. 4 e–N relation of dense density type

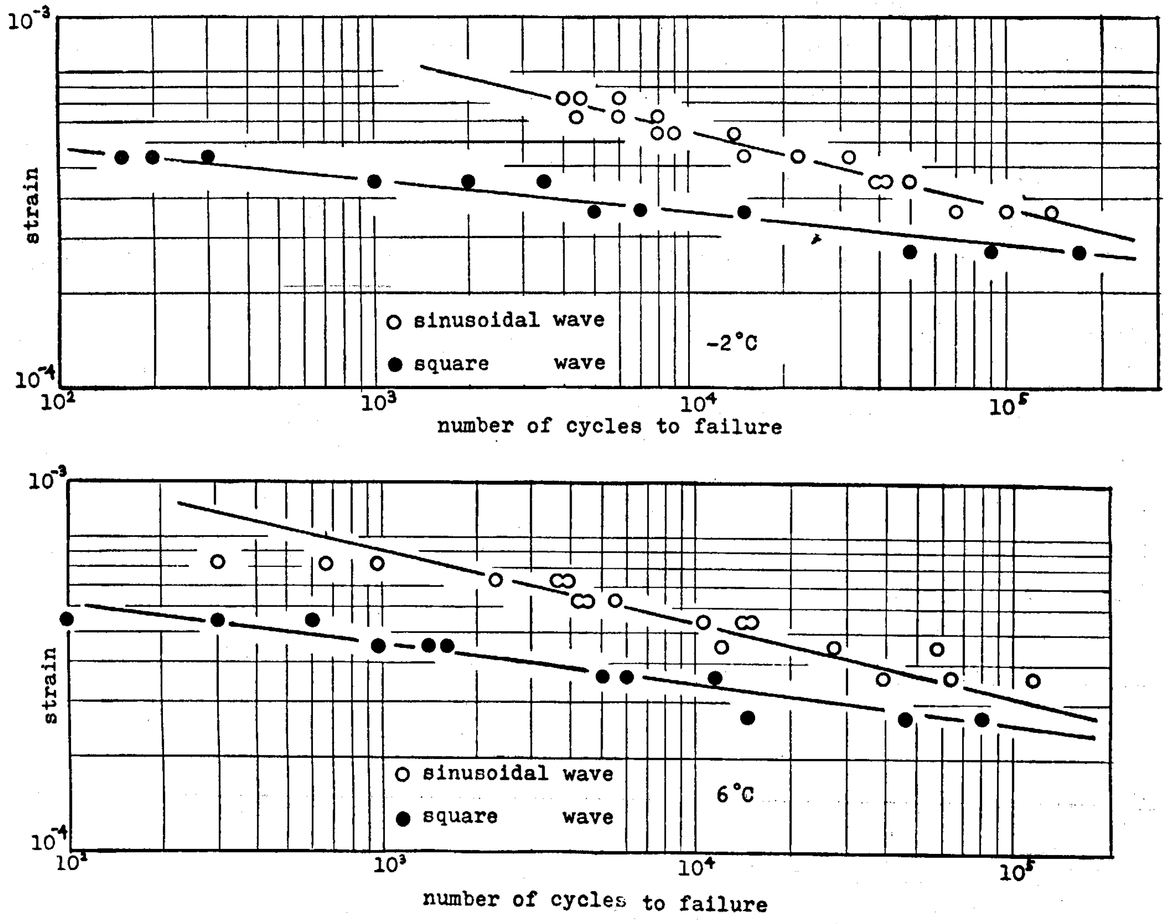

Fig. 5 e–N relation of coarse density type.

a) Dense density type

In case of temperature being $-2°C$

Sinusoidal wave: $N=(10)^{-27.812}\ (1/\varepsilon)^{10.111}$

Square wave : $N=(10)^{-21.828}\ (1/\varepsilon)^{7.623}$ ·········(1)

In case of temperature being 6°C

Sinusoidal wave: $N=(10)^{-12.108}\ (1/\varepsilon)^{4.964}$

Square wave : $N=(10)^{-19.784}\ (1/\varepsilon)^{6.928}$ ·········(2)

b) Coarse density type

In case of temperature being $-2°C$

Sinusoidal wave: $N=(10)^{-9.285}\ (1/\varepsilon)^{4.164}$

Square wave : $N=(10)^{-29.121}\ (1/\varepsilon)^{9.605}$ ·········(3)

In case of temperature being 6°C

Sinusoidal wave: $N=(10)^{-9.939}\ (1/\varepsilon)^{4.251}$

Square wave : $N=(10)^{-23.177}\ (1/\varepsilon)^{7.827}$ ·········(4)

In these figures, gap between sinusoidal wave and square wave is larger than that of straight asphalt, and number of cycles to failure in dense density type is about two or three times as much number as coarse density type mixture. Furthermore, in case of temperature being 14°C, comparison between gumphalt and straight asphalt can be done by Fig. 6. From this figure, number of cycles to failure in gumphalt mixture is

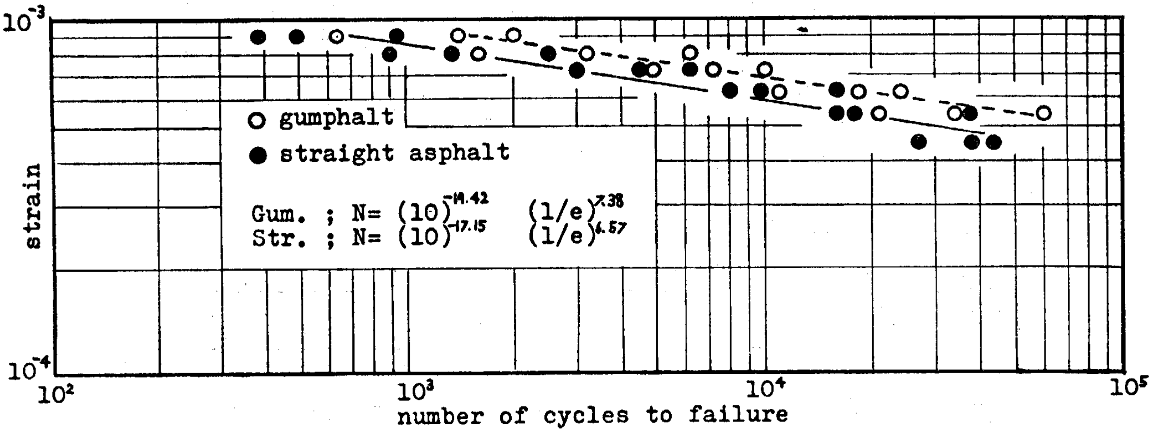

Fig. 6 e–N relation of 14°C.

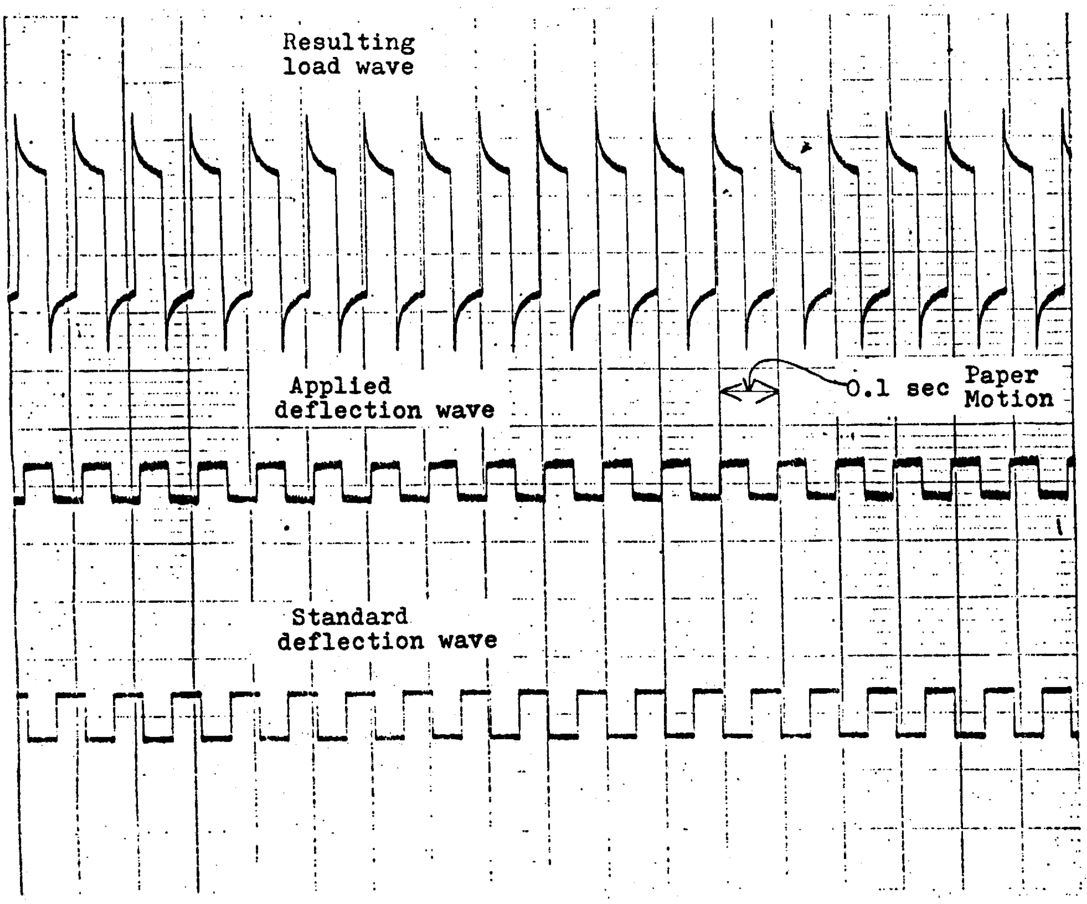

Fig. 7 Resulting load wave in case of temperature being 14°C (straight asphalt)

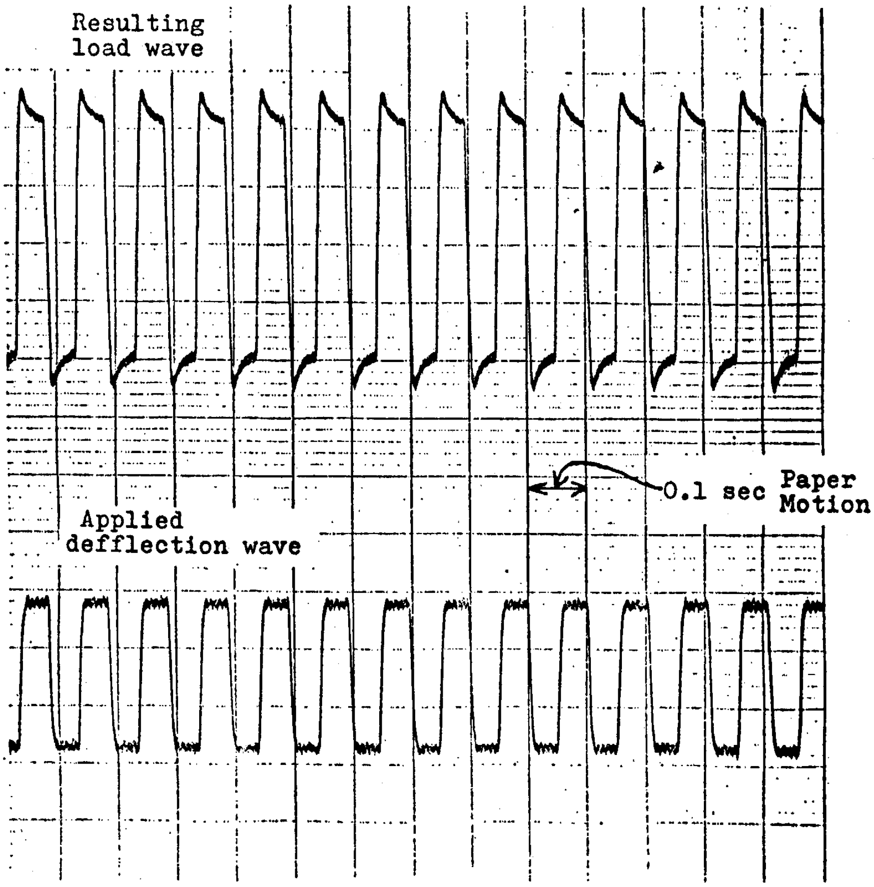

Fig. 8 Resulting load wave in case of temperature being $-2°C$ (gumphalt).

also about twice as much number as that of straight asphalt. And, it can be obviously observed that there exist an phenomenon of stress relaxation in resulting square wave of dynamic test. Resulting load wave due to square wave is represented in Fig. 7 and Fig. 8. Figure 7 indicate result of straight asphalt, and Figure 8 indicate result of gumphalt. From these figures, it can be easily understood that stress relaxation of gumphalt is smaller than straight asphalt. In this respect, theoretical consideration is done as following. If viscoelastic model is three element solid and strain history is

$$\varepsilon(t)=\begin{cases}\varepsilon_1 t/t_1; & 0<t<t_1\\ \varepsilon_1 & ;\ t_1<t\end{cases} \qquad \cdots\cdots\cdots(5)$$

the solution in case of $t_1<t$, is followings by using of hereditary integral[6)]

$$\sigma(t)=\varepsilon_1 q_0+\varepsilon_1/t_1(q_0 p_1-q_1)(1-e^{t_1/p_1})e^{-t/p_1} \qquad \cdots\cdots\cdots(6)$$

at the limit of $t_1=0$, upper equation become

$$\lim_{t_1\to 0}\sigma(t)=\lim_{t_1\to 0}\{\varepsilon_1 q_0+\varepsilon_1/t_1(q_0 p_1-q_1)(1-e^{t_1/p_1})e^{-t/p_1}\}$$
$$=\varepsilon_1 q_0-\{\varepsilon_1(q_0 p_1-p_1)e^{-t/p_1}\}/p_1$$

So, when constant strain act on viscoelastic body, stress relaxation obeys the equation of (3). Decrease of stress is largely influenced by the value of p_1, and p_1 of gumphalt is larger than p_1 of straight asphalt. Fig. 9 represents stress ratio

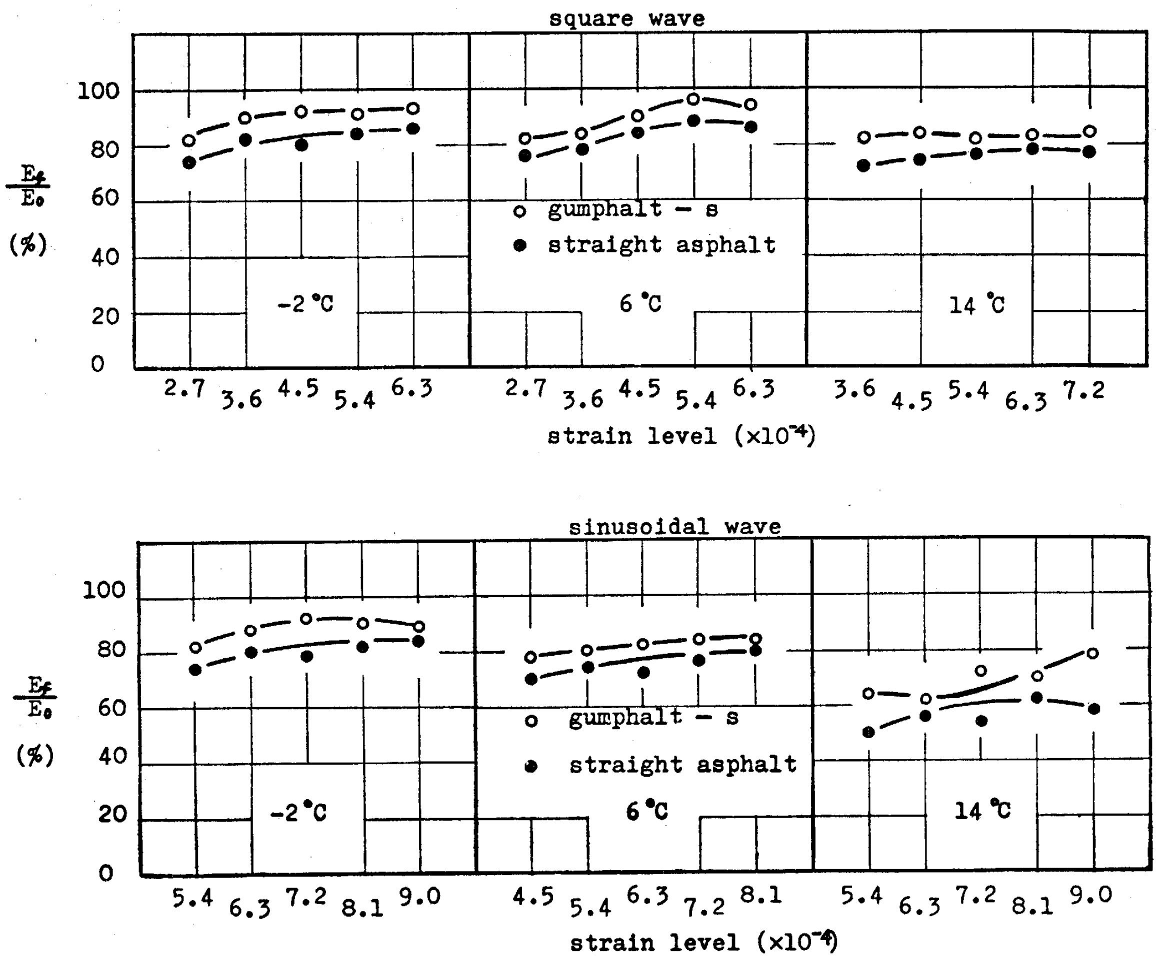

Fig. 9 Stress ratio in every temperature.

Conclusion

From these experimental results following conclusion will be said as the viscoelastic nature of gumphalt.

a. In constant rate of strain test, viscoelastic constants of gumphalt are generally larger than that constants of straight asphalt, and this tendency is distinct fact in case of temperature being 14°C or more over.

b. In dynamic test, the number of cycles to failure in gumphalt and straight asphalt are about the same value, when temperatures are −2°C and 6°C. But, in case of temperature being 14°C or more over, number of cycles to failure in gumphalt mixture is about twice as much number as that number of straight asphalt mixture.

c. In dynamic test by square wave, it can be obviously observed that there exist an phenomenon of stress relaxation, and stress relaxation of gumphalt is smaller than that of straight asphalt. This can be easily understood by the figure 7 and 8.

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