Chapter 2

Shear test for rubbers at normal temperature

2.1 Summary

Here, shaking tests are conducted for frequency range from 0.2 to 15 Hz at normal temperature (near 23 °C).

A specimen used in the tests is explained in Section 2.2, the general description for the experimental apparatus is provided in Section 2.3 and the testing method is described in Section 2.4. The test results are given and studied in Section 2.5.

2.2 Specimen

2.2.1 Shape of specimen

Fig. 2.1 shows a photo of a shear test specimen of seismic isolation/vibration-absorption rubbers and Fig. 2.2 is a dimensional drawing of the specimen. The specimen is formed with three rectangular blocks of metal onto which two rubber blocks are glued. A jig of a rectangular shape with a circular hole is fixed onto the specimen with screws, which prevent the specimen from being deformed during the loading. Fig 2.3 presents a photo of the specimen with the attached jig. Fig. 2.4 illustrates undeformed and deformed rubber blocks in a specimen in a shear test.

Fig. 2.1 Specimen for shear tests

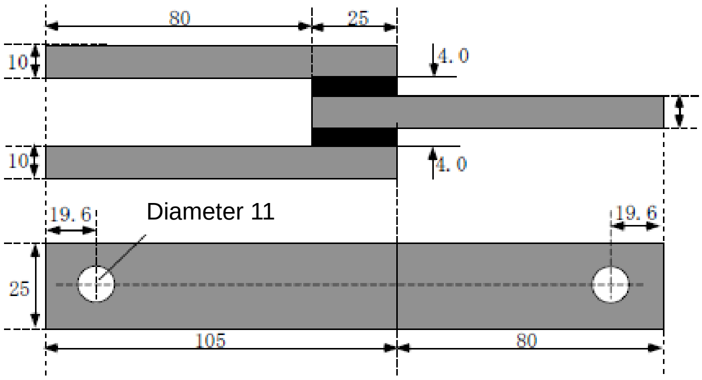


Fig. 2.2 Dimensions of specimen for shear tests (unit: mm)

Fig 2.3 Specimen with a jig

(a) Before deformation (b) After deformation

Fig. 2.4 Undeformed and deformed rubber block in a specimen

2.2.2 Kinds of rubber

Four kinds of rubber materials are prepared, which are different in hardness and damping characteristics and whose names are defined in Table 2.1. tanδ in the table is called the loss coefficient, which indicates the size of damping characteristics (due to internal friction) of rubber materials. NLL, NLS, NSS and NSL are abbreviated names of these kinds of rubber materials, which are used hereafter in this report.

Table-2.1. Rubber materials

Material	Natural Rubber	Natural Rubber	Natural Rubber	Natural Rubber
Hardness	65	50	50	65
tanδ	0.27	0.20	0.03	0.05
Young's module [MPa]	9.71	5.52	3.60	7.39
Specific heat [J/g･K]	1.40	1.47	1.55	1.43
Heat conductivity [W/m･K]	0.22	0.22	0.23	0.23
Abbreviated name	NLL (**L**arge damping **L**arge hardness)	NLS (**L**arge damping **S**mall hardness)	NSS (**S**mall damping **S**mall hardness)	NSL (**S**mall damping **L**arge hardness)

2.3 Experimental apparatus

2.3.1 General outline

A series of material tests is conducted to understand the dynamic viscoelastic property of rubber materials at normal temperature. In the tests, both ends of a specimen are fixed by friction to the shear testing machine, and strain is given to the specimen by shaking a vibration table. In order to increase the frictional force, we carved chases at 3mm intervals on the sections that pinched the specimen. Input waves were controlled externally by a PC equipped for data input/output and given to the vibration table to quake a specimen with seismic isolation/vibration-absorption rubbers. In order to horizontally deform the specimen, the loading was provided along a linear guide. Values of loading, displacement, and acceleration onto the specimen were brought into the PC via the dynamic strain measuring equipment. The outline of these control and measuring equipments are schematized in Fig. 2.5.

In the tests, temperatures were measured with an infrared camera. Shooting the specimen with the infrared camera enables us to observe the temperature distributions and temperature changes before and after deformations. The camera was fixed on the platform to shoot the specimen horizontally from the front side. This platform is shown in Fig. 2.6, and the infrared camera arrangement is in Fig. 2.7.

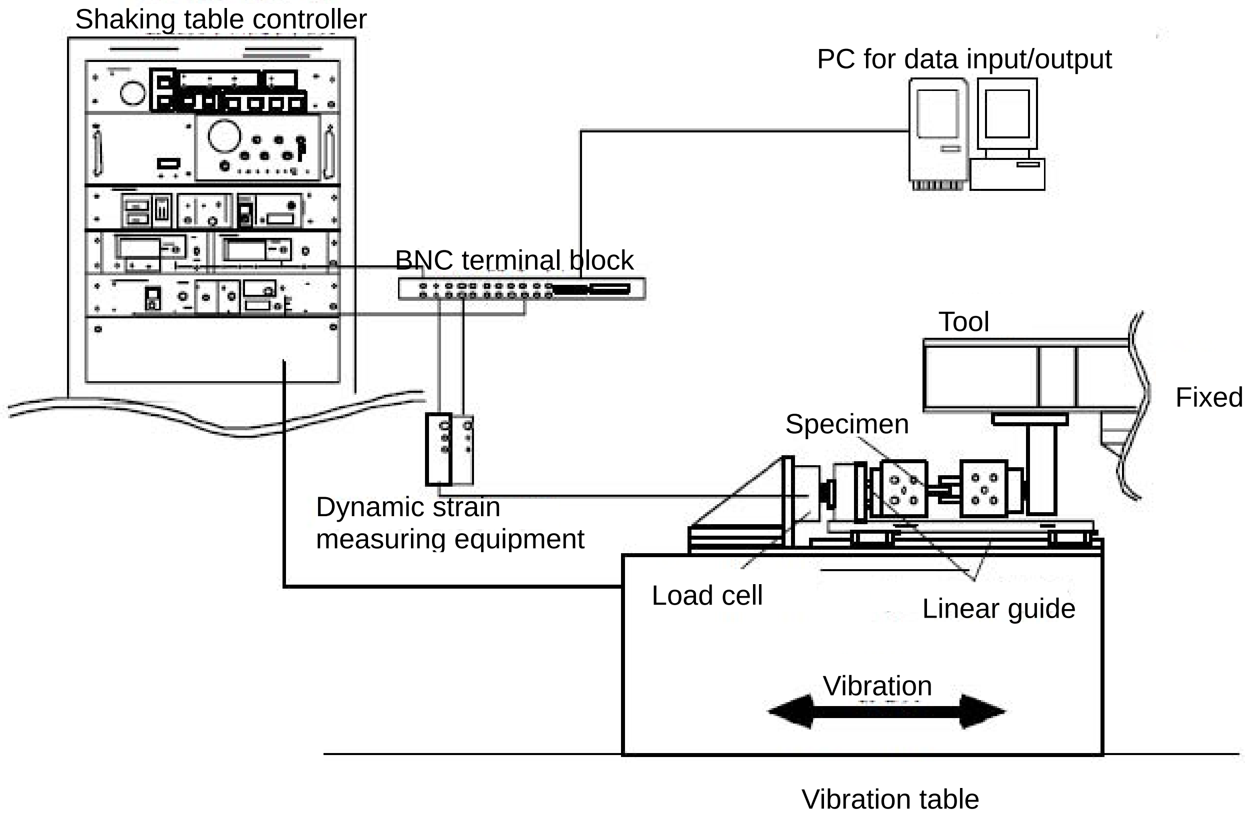


Fig. 2.5 Outline of control and measuring equipments

Fig. 2.6 A tool arranged under an infrared camera

Fig. 2.7 An infrared camera arrangement

2.3.2 Loading equipment

In the tests, we shook a specimen with seismic isolation/vibration-absorption rubber by using a vibration table and measured the values of loading, displacement and acceleration of the specimen. Shaking power of the vibration table is 5000 kgf, and its direction is only in the horizontal direction. Figs. 2.8 and 2.9 show photos of a body of the vibration table and control equipment. Table 2.2 indicates the specifications of the vibration table.

The vibration table was controlled by a computer program executed on a PC equipped for data input/output and its wabe data were inputted externally. Fig. 2.10 shows a photo of the PC for data input/output. Since the attached control equipment does not have a function to set the number of cycles, it was also controlled by external input data. By externally inputting, the amount of displacements was converted to power voltage, which was inputted to the vibration table to be operated. Voltage 5V is equivalent to the amplitude of approximately 25 mm of the vibration table. The data of the load, displacement and acceleration obtained by the loading on the vibration table were obtained from the input/output PC.

Three sets of linear guides were attached to the vibration table and one of them is shown in Fig. 2.11. The first and the second sets were arranged between jigs to bookend a specimen without friction. The third set was placed on the vibration table. The vibration of the specimen via the third one enables the specimen to deform only in the horizontal direction (Fig. 2.12). In addition, one linear guide consists of two guides and one rail. For measuring load applied to the specimen, a load cell was arranged at the side of the specimen to be pinched between the jigs.

Fig. 2.8 Shaking table body

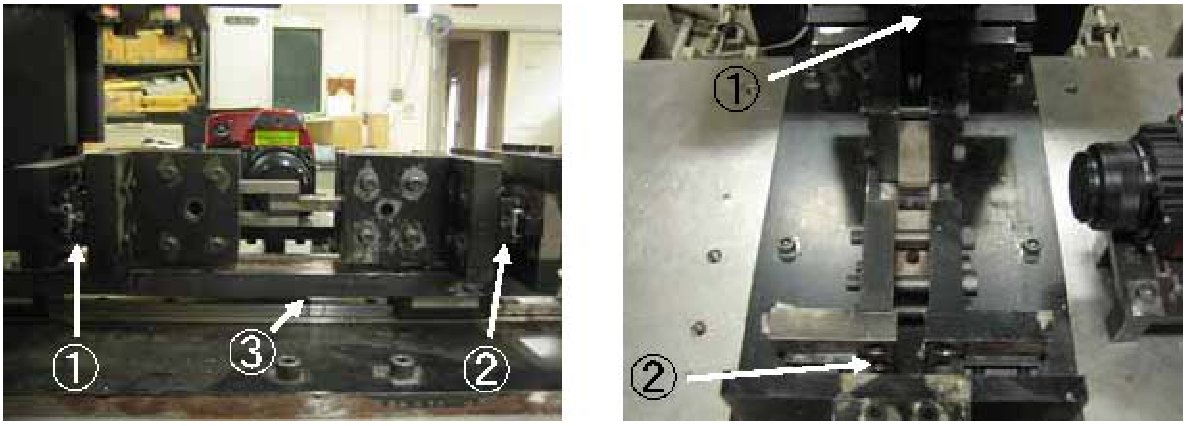

Fig. 2.9 Control equipment of the shaking table

Table 2.2 Specifications of vibration table

Table size	1000mm×1000mm
The maximum capacity loading	3000kgf
Excitation force	5000kgf
Excitation direction	Horizontal only
Maximum amplitude	±25mm (±5v)
Maximum acceleration	±2.0G (±5v)
Maximum overturning moment	0.4ton-m


Fig. 2.10 PC for data input/output


Fig. 2.11 Linear guide



(a) Side view (b) Overhead view

Fig. 2.12 Linear guide arrangement

2.3.3 Measuring equipment

A load cell, in which strain gauge values are converted to the load values electrically, was used to measure the loads applied on a specimen. The maximum loading capacity of the load cell, which was fixed with by jig, was 10 kN. A photo of the load cell is shown in Fig. 2.13 and its specification is provided in Table 2.3.

A hot-air generator was used to adjust the specimen's temperature. The specimen was covered by a foam carton so that its temperature was maintained at a fixed temperature. The appearance is shown in Fig. 2.14. The hot-air generator takes air at a suction port, and belches heated hot air out of a discharge port. Its temperature is adjusted by winding a temperature adjustment dial. A photo of the hot-air generator and its specification are shown in Fig. 2.15 and Table 2.4, respectively.

In order to measure the specimen's initial temperature and its temperature distribution before and after its transformation, we captured images with an infrared camera. A photo and specification of the infrared camera are described in Fig. 2.16 and Table 2.5, respectively.

The data of load, displacement and acceleration were converted to the corresponding values of voltage by using the dynamic strain measuring equipment, and brought into the PC. A photo and its specification are respectively given in Fig. 2.17 and Table 2.6.

Fig. 2.13 Load cell

Manufacturer	Tokyo Sokki Kenkyujo CO.,LTD.
Model TCML-1	0KNB
Capacity 10	kN
Reference in weight	1.02tf
Rating output	2.5mV/V(5000×10^{-6} strain)±0.5%
Allowable temperature range	-30+80°C
Allowable overload	150%
Recommended impressed voltage	10V or less
Allowable impressed voltage	20V

Fig. 2.14 Specimen under temperature control

Fig. 2.15 Hot-air generator

Table 2.4 Specification of hot-air generator

Name	Multi-dryer HAS-10
Manufacturer	TAKETSUNA MANUFACTORY CO., LTD.
Rating	Continuous
Ambient temperature/humidity	0 ~ +40 °C
Temperature control range (Accuracy)	Normal to 350°C (±10% FS, Phase control)
Bore diameter of hot-air outlet	φ50mm (SUS pipe)
Maximum output	0.13 / 0.16(12W)
Maximum airflow capacity 50 /60 *Hz*	1.0 /1.2m^3 / min
Maximum static pressure 50 /60*Hz*	0.14 / 0.21*kP*a
Maximum noise 50/60*Hz*	47 / 50*d*B
Suction air temperature	Normal temp
Airflow control system	Slide shutter (Damper)
Mass	5.2kg

Fig. 2.16 Infrared camera

Table 2.5 Specification of infrared camera

Name	Advanced Thermo
Manufacturer	Nippon Avionics Co., Ltd.
Detector	Uncooled 2D FPA
Number of elements	320 (H) x 240 (V)
Number of display pixels	320 (H) x 240 (V)
Wavelength	8 ~ 14 μm
View angle	30.6° (H) x 23.1°(V)
Momentary view angle	1.68 mrad
Lowest temperature resolution	0.1 °C or less
Temperature measurement range	Low-Range: -20°C to 120°C High-Range: 100 to 300°C
Number of display frames	1/60 second
Focus	Manual

Fig. 2.17 Dynamic strain measuring equipment

Table 2.6 Specification of dynamic strain measuring equipment

Name	Dynamic strainmeter DA－16A
Manufacturer	Tokyo Sokki Kenkyujo CO., LTD.
Rating output (RO)	1~10V
Sensitivity adjustment (SENS)	Rating o utput 1V : 50 ~ 5000×10^{-6} strain (1×10^{-6} strain step) can be specified
	Rating output10V: 500 ~ 10000×10^{-6} strain can be specified
	Fine tuning (I. SENS): 1/10 ~ 1 (OUT-I only)
Sensitivity	50×10^{-6} strain (Bridge excitation 2Vrms)
	OUT-V 1V(5kΩ loading) OUT-I 12mA or more (30 Ω loading)
Maximum output	OUT-V ±10V(5k Ω loading)
	OUT-I ±50mA(30 Ω loading, 120 Ω with bridge) or ±10V(5k Ω loading)
Measurement range	±50000×10^{-6} strain (Bridge excitation 2Vrms)
Proofreading output	±(RO, RO/2) Accuracy ±0.5%
Temperature/humidity range	-10 ~ +50 °C 85%RH or less (excluding dew condensation)

2.4 Testing method

2.4.1 Preparation

In preparation for the actual tests, we created functions of waveforms for the vibration table.

The following three kinds of waves were prepared to be sent to the table:

$$u_1 = A\sin\omega t \tag{2.1}$$

$$u_2 = 0.3A\sin 6\omega t + A\sin\omega t \tag{2.2}$$

$$u_3 = A\cdot\frac{1+\cos 0.1\omega t}{2}\sin\omega t \tag{2.3}$$

where u_1, u_2 and u_3 are the displacements and A is the amplitude. In what follows, we call u_1 Sine wave, u_2 Random wave 1 and u_3 Random wave2. The amplitudes of Random waves 1 and 2 were set at the maximum amplitude (8mm, 12mm) of each rubber material in Sine wave; that is, Random wave 1 has amplitudes of 6.3 mm and 9.5 mm, respectively. Figs. 2.18 and 2.19 show the waveform profiles of Random waves 1 and 2.

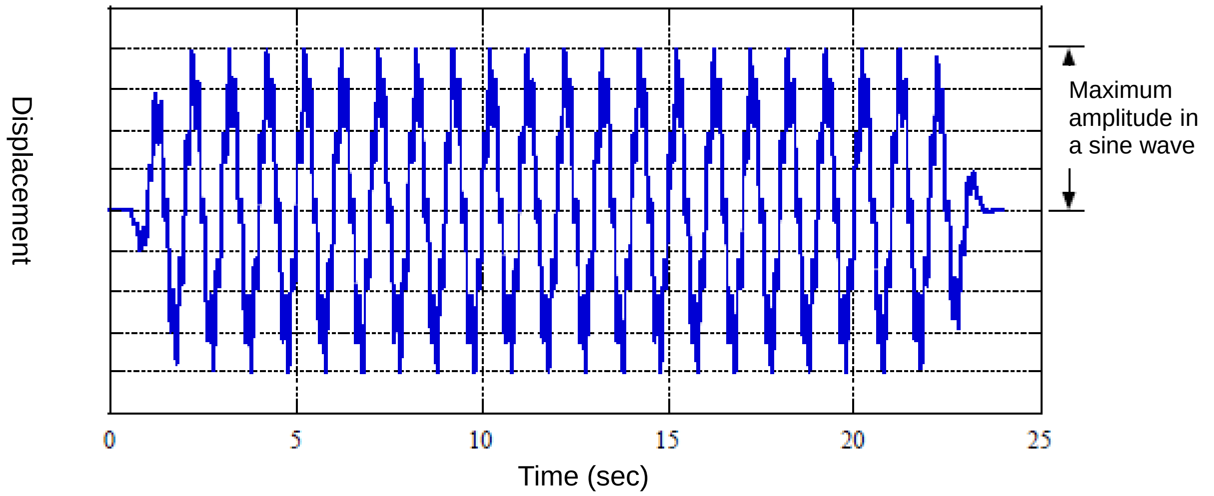


Fig. 2.18 Random wave 1 (amplitude 6.3 ~ 9.5 mm, frequency 1 Hz, number of cycles 24)

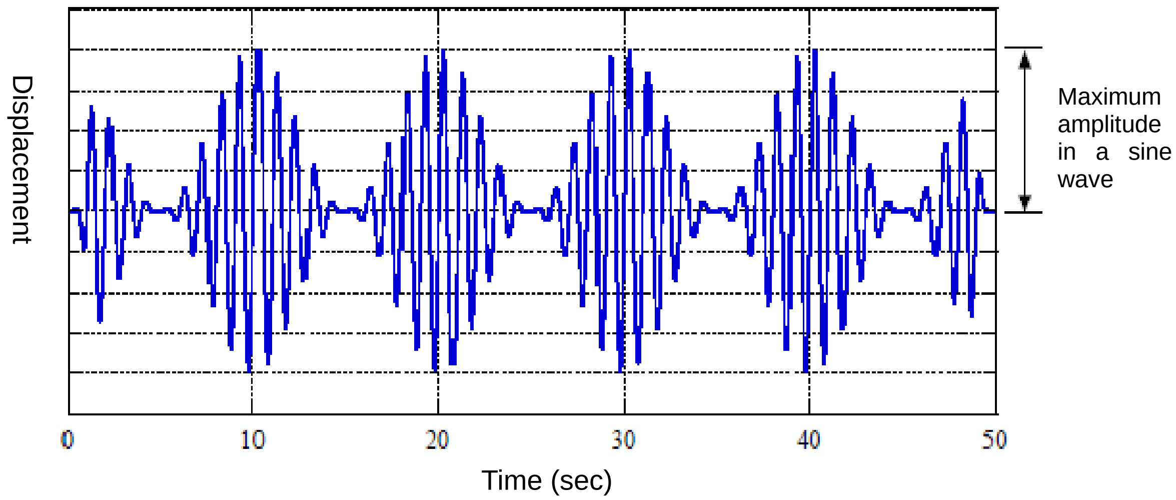


Fig. 2.19 Random wave 2 (amplitude 8 ~ 12 mm, frequency 1 Hz, number of cycles 50)

2.4.2 Measuring method

We controlled the vibration table with the PC equipped for data input/output and gave waves to the specimen. The data of load and displacement were brought into the PC. We also obtain the image data by using the infrared camera at the same time (Fig. 2.20).

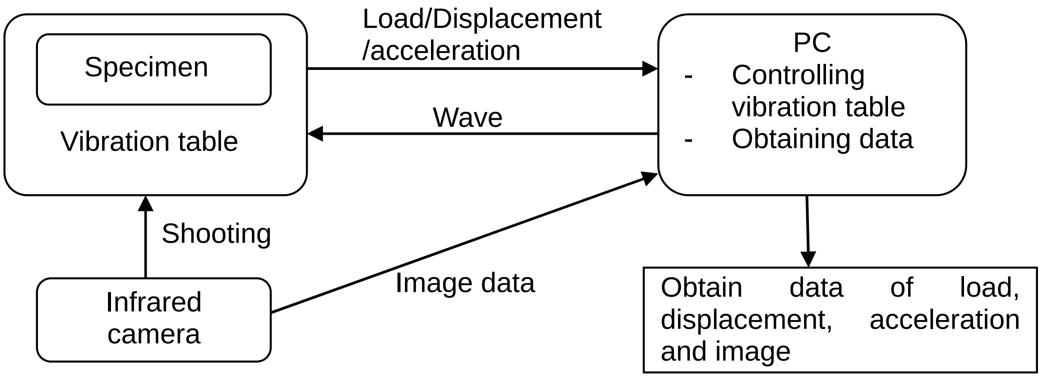


Fig. 2.20 Mesuaring method

2.4.3 Preliminary test

We conducted a preliminary test in order to confirm the excitation accuracy of the vibration table before the main tests. It was found that the displacement data of the wave we sent were not consistent with that of the table, when generating waves by moving the table. Accordingly, we multiplied the amount of displacement sent to the table by constants and adjusted the actual amount of displacement of the table. Table 2.7 indicates the displacement values that we actually sent to the table. Here, knowing that voltage 5V is equivalent to the amplitude of about 25V, we divided its value with unit mm by 5 to obtain the value with unit V. The vibration table has control gain. When this value is large, the difference between the displacement values send to the table and the actual values of displacement of the table become small. Therefore, we conducted the test by setting the control gain at the maximum value of 10.

In order to obtain the high accuracy of the displacement and load data, we sent a wave of displacement 0 to the vibration table right after the specimen was arranged, and obtained the values to set as an initial position. Corrections were made by taking the values from displacement data.

The load cell used in the tests inevitably measures the inertia force due to the jig weight when the table is moved, in addition to the load applied to rubber materials. In order to remove this inertia force, we firstly tested only with testing jigs on the vibration table and identified its effective net weight. The load values measured in this time-load relation is clearly the inertial force generated from the material weight. Therefore, we removed this inertia force by subtracting the value of the identified net weight multiplied by acceleration obtained from test from the load value at the test. Fig. 2.21 compares the waveforms obtained when the load measured by the mass identification and the identified mass (18.5 kg) multiplied by the acceleration were applied.

Table 2.7 Displacement values that were actually sent to the vibration table at each amplitude/frequency (Unit [V])

Number of Frequency / Amplitude	0.2 Hz	0.5 Hz	1 Hz	2 Hz	5 Hz	10 Hz	15 Hz	Inputted displacement
1 mm (0.2V)	0.242	0.24	0.239	0.236	0.218	0.198	0.186	Sine wave
2 mm (0.4V)	0.4696	0.468	0.466	0.452	0.42	-	-	
4 mm (1.0V)	0.9224	0.916	0.9	0.88	0.824	-	-	
6 mm (1.2V)	1.362	1.344	1.3332	1.308	1.248	-	-	
8 mm (1.6V)	1.7984	1.76	1.72	1.752	1.68	-	-	
10 mm (2.0V)	2.24	2.19	2.17	2.14	2.06	-	-	
12 mm (2.4V)	2.64	2.616	2.592	2.544	2.496	-	-	
6.3 mm (1.26V)	-	-	1.3545	-	-	-	-	Random wave 1
9.5mm (1.90 V)	-	-	2.033	-	-	-	-	
8mm (1.6 V) -		-	1.72 -		-	-	-	Random wave 2
12mm (2.4 V)	-	-	2.592	-	-	-	-	

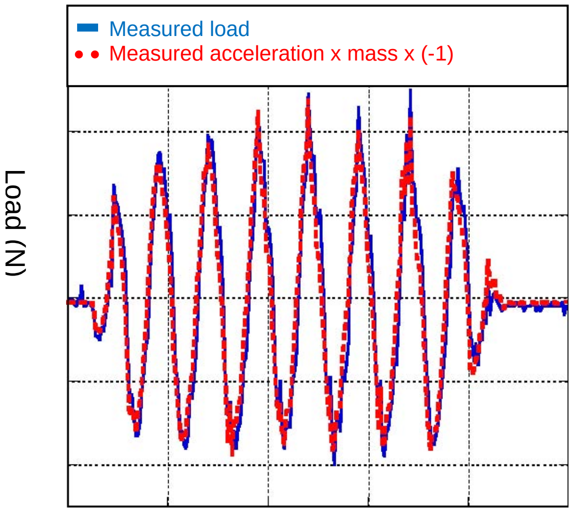


Fig. 2.21 Measured loads and accelerations x mass (19kg)

2.4.4 Material tests at normal temperature

Using three types of waveforms as input, we conducted dynamic loading tests for rubber materials at normal temperature. Initial temperature was set at 23 °C, which was assumed to be a normal temperature, with allowable temperature range of ±2 °C. When ambient or room temperature is low, the specimen was covered by a foam carton and hot air was sent to adjust the initial temperature before loading.

The amplitude of Sine wave was changed from a minute value of 1 mm to a large one of 8mm in the case of NLL. On the other hand, the amplitude was changed up to 12 mm in the case of NLS and the loading was applied in ascending order. Although NSS was originally planned to be loaded up to the amplitude of 12 mm, the specimen was ruptured at the 10 mm loading and, therefore, only the data up to those loading levels are taken for reference. Fig. 2.22 shows the ruptured specimen. The frequency level was changed from low frequency of 0.2 Hz to high 5Hz. For minute amplitude of 1 mm, tests with frequencies of 10 Hz and 15 Hz were also conducted. To obtain stable waveform data, Sine wave was set to be continuous 5 cycles.

For Random waves 1 and 2, only one pattern of loading was given to each rubber; amplitudes for NLL, NSL and NSS were 6.3 mm for Random wave 1 and 8 mm for Random wave 2, and that of NLS is 9.5 mm for Random wave 1 and 12 mm for Random wave 2. The loading frequency was 1 Hz and was common to all kinds of rubbers. The number of cycles was 24 cycles for Random wave 1 and 50 cycles for Random wave 2.

Data of displacement and acceleration were obtained from the vibration table, while the loading data applied to rubber materials were obtained from the load cell. Temperatures were measured by the infrared camera placed on the vibration table. In order to keep the loading conditions the same, approximately 5 minutes interval were taken between tests so that the specimen went back to its original temperature. The actual loading patters employed in the tests are shown in Table 2.8.

Fig. 2.22 Ruptured specimen

Table 2.8 Loading patterns for material tests at normal temperature

Number of Frequency / Amplitude	0.2Hz	0.5Hz	1Hz	2Hz	5Hz	10Hz	15Hz	Inputted displacement
1mm	○	○	○	○	○	○	○	Sine wave
2mm	○	○	○	○	○ -		-	
4mm	○	○	○	○	○ -		-	
6mm	○	○	○	○	○ -		-	
8mm	○	○	○	○	○ -		-	
10mm	○	○	○	○	○ -		-	
12mm	○	○	○	○	○ -		-	
6.3mm	- -		○	- - -			-	Random wave 1
9.5mm	- -		○	- - -			-	
8mm	- -		○	- - -			-	Random wave 2
12mm	- -		○	- - -			-	

2.5 Test results and study

In this section, we present the material test results at normal temperature. Shear strain γ and stress τ [N /mm^2] were respectively obtained from the displacement and load data measured in experiments. We correct those values with the initial position of the vibration table and with the inertia force due to the acceleration and compare them with each other. Here, the shear strain of the rubber is the value obtained by dividing the horizontal shear displacement u by the rubber piece thickness t (=4 [mm]), while the shear stress is the value obtained by dividing the load P applied on the rubber by 2 (because one specimen has two pieces of rubber) and by the rubber piece area A (= 25x25 [mm^2]).

$$\gamma = \frac{u}{t} \tag{2.4}$$

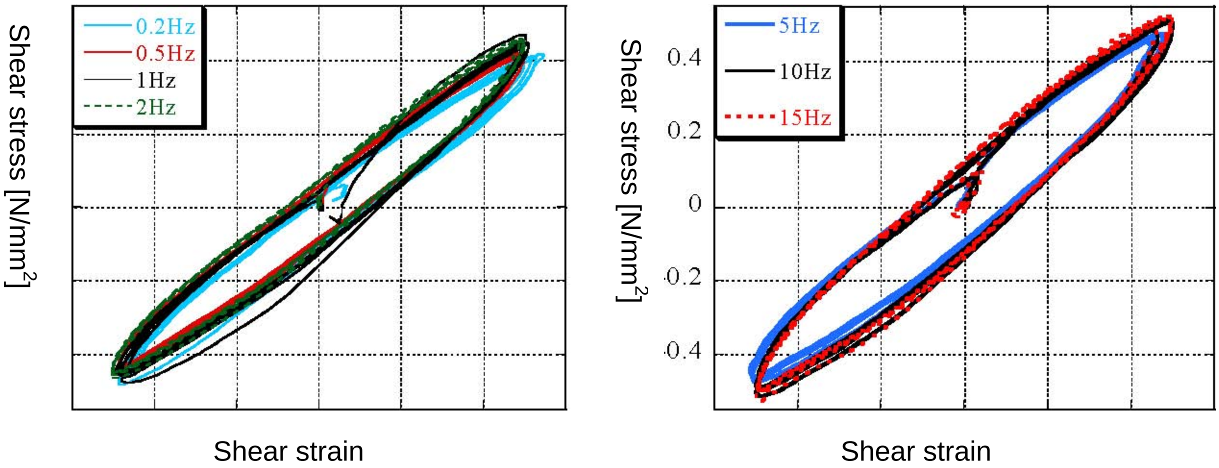
$$\tau = \frac{P}{2A} \tag{2.5}$$

2.5.1 Material tests by sine wave loading

Figs. 2.23, 2.24 and 2.25 show the stress-strain relations of sine waves of NLL, NLS and NSS at initial temperature 23 °C with 1 mm amplitude and 0.2 – 15 [Hz] frequencies, respectively. The maximum shear strain value is about 0.25, which is equivalent to 1 mm amplitude. As the frequency increases, the inclination of history curves and its area tend to increase, but the changes are small. The stress-strain relation for NSS exhibits almost elastic behaviors.

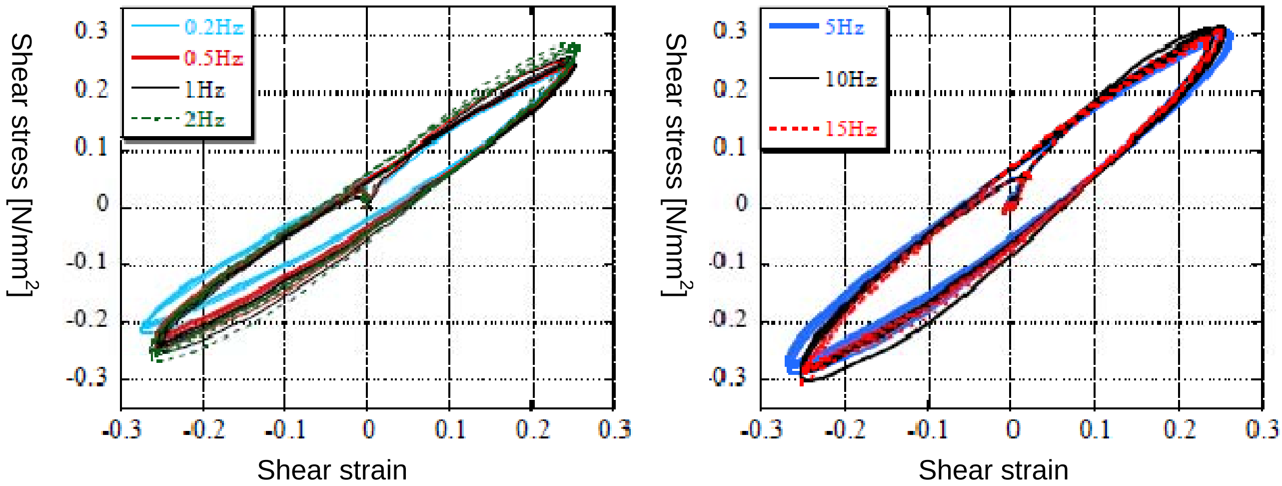
Figs. 2.26, 2.27 and 2.28's (a) to (e) show the stress-strain relations of Sine waves of NLL, NLS and NSS under at initial temperature 23 °C with 0.2 – 5 [Hz] frequencies. For all the materials, history loops of the first cycle are larger than those of the second or later. As the frequency and amplitude increase, the differences became large. As the strain increases, the shapes of these history curves for NLL and NLS change from a simple ellipse to an ellipse with corners and the hardening behavior with rapid stress increase becomes prominent. The values of shear strain at which the hardening behavior initiates depends on the materials. In NLL, it starts around ±1.5, while in NLS around ±2.5.

Accordingly, it can be said that rubber materials with small hardness tend to reveal the hardening behavior with small strain than those with large hardness.



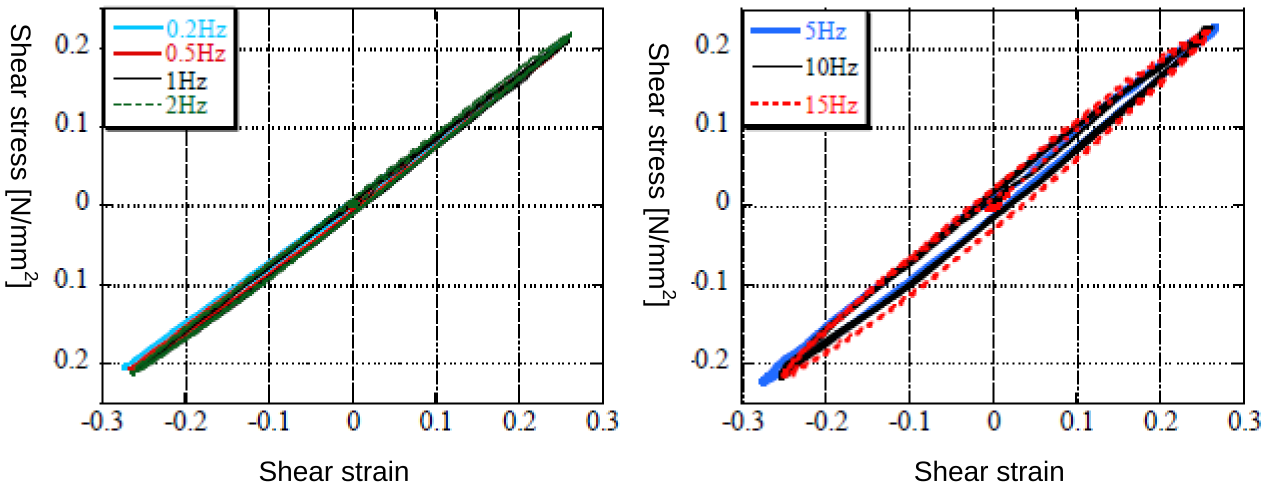
(a) Frequency 0.2 – 2 [Hz]
(b) Frequency 5 – 15 [Hz]

Fig. 2.23 Stress-strain relations for Sine wave NLL at initial temperature 23 °C with 1 mm amplitude



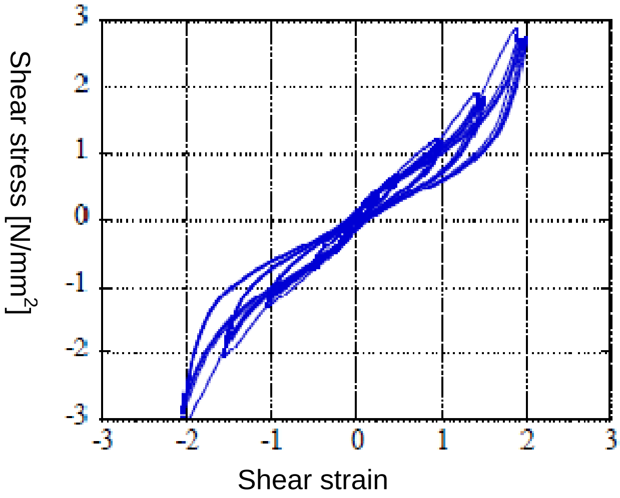
(a) Frequency 0.2 – 2 [Hz]
(b) Frequency 5 – 15 [Hz]

Fig. 2.24 Stress-strain relations for Sine wave NLS at initial temperature 23 °C with 1 mm amplitude

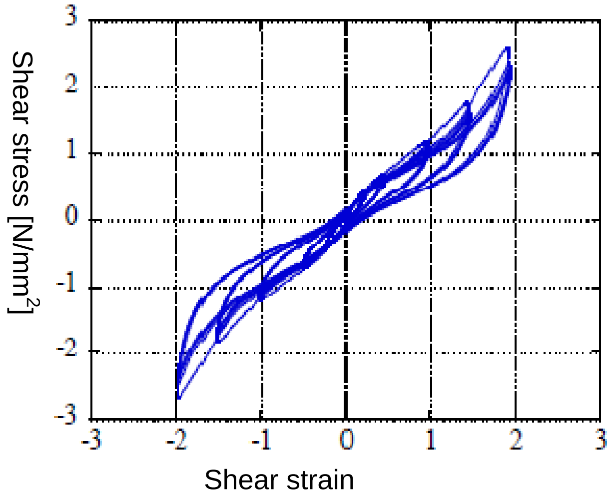


(a) Frequency 0.2 – 2 [Hz]
(b) Frequency 5 – 15 [Hz]

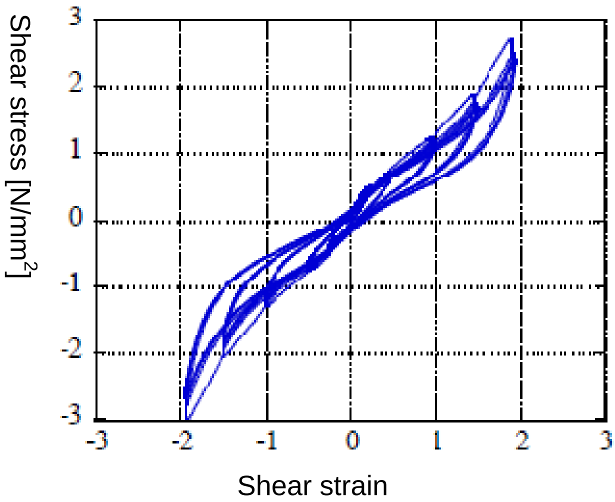
Fig. 2.25 Stress-strain relations for Sine wave NSS at initial temperature 23 °C with 1 mm amplitude



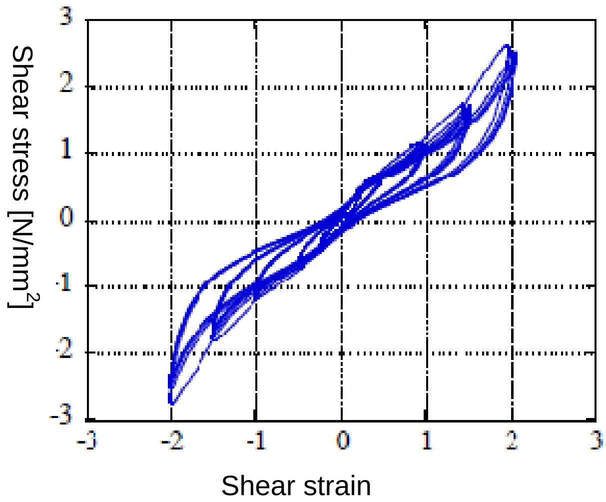
(a) Frequency 0.2 [Hz]



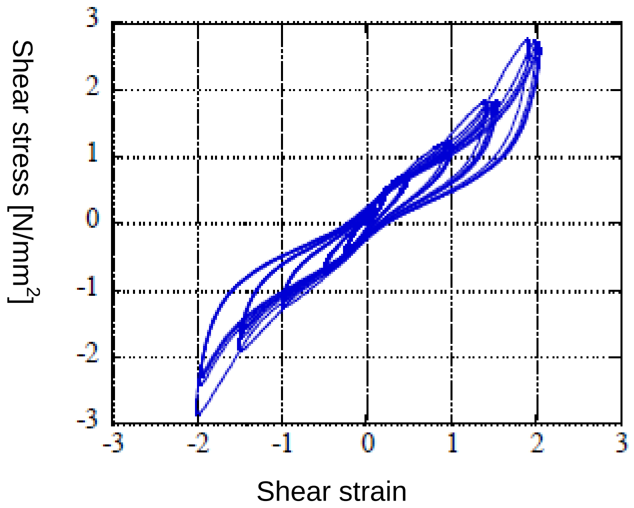
(b) Frequency 0.5 [Hz]



(c) Frequency 1 [Hz]

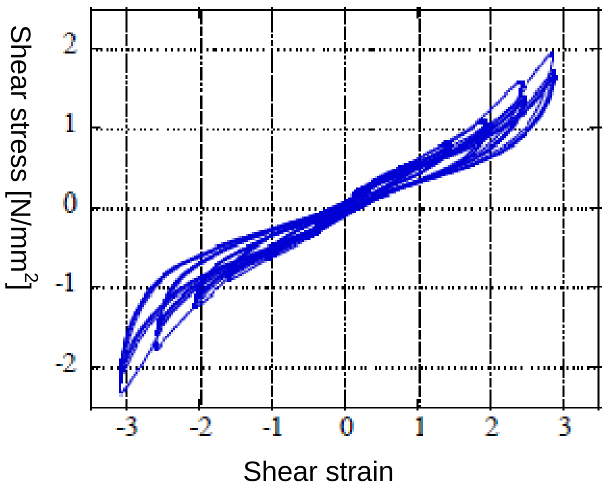


(d) Frequency 2 [Hz]

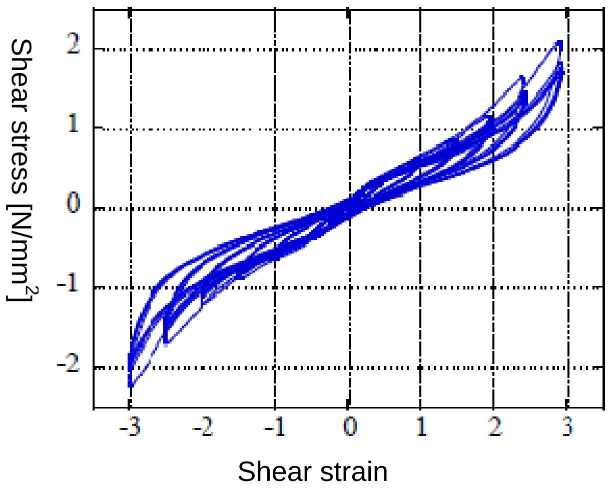


(e) Frequency 5 [Hz]

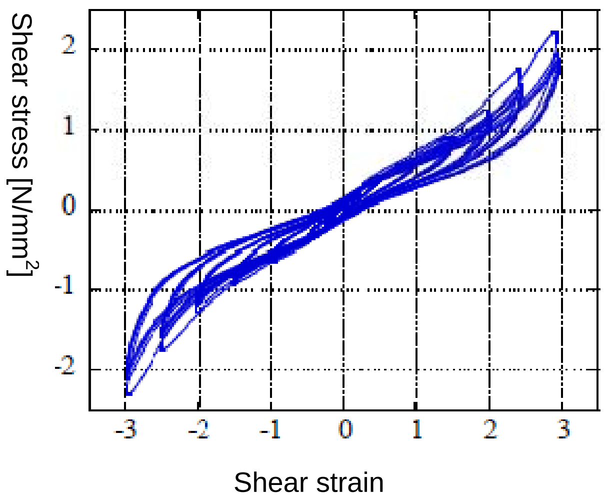
Fig. 2.26 Stress-strain relations of Sine wave NLL at initial temperature 23 °C with 0.2-5 [Hz] frequency



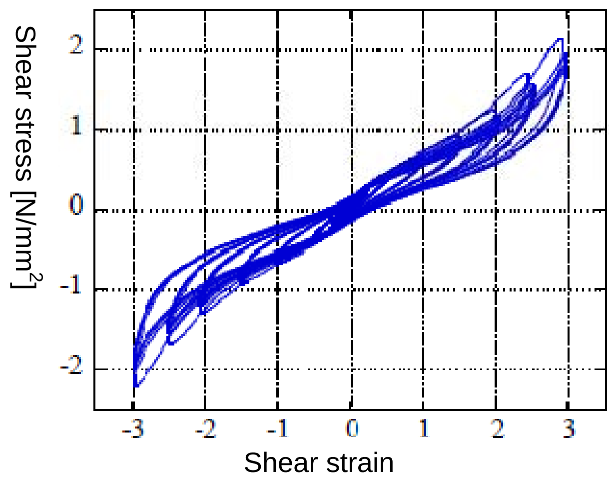
(a) Frequency 0.2 [Hz]



(b) Frequency 0.5 [Hz]



(c) Frequency 1 [Hz]



(d) Frequency 2 [Hz]

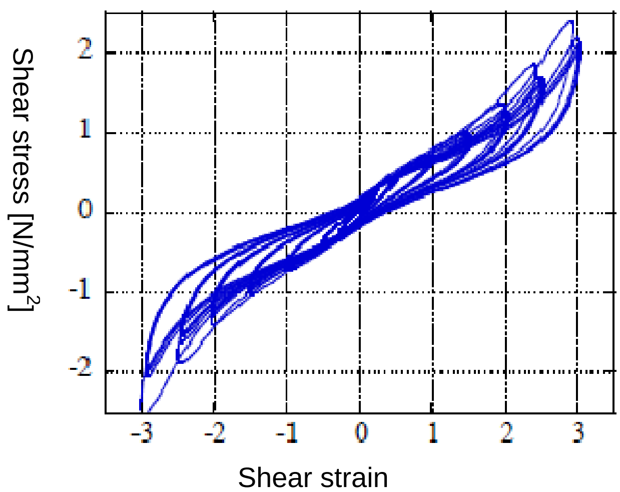
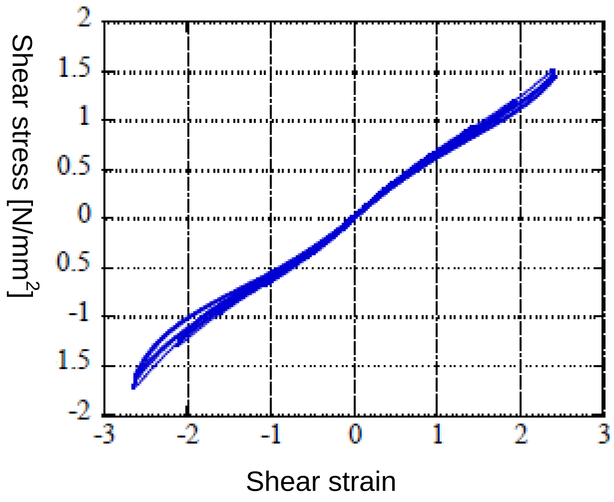
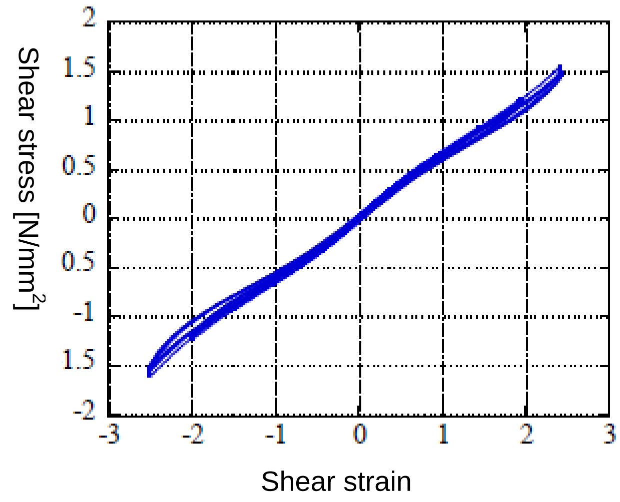


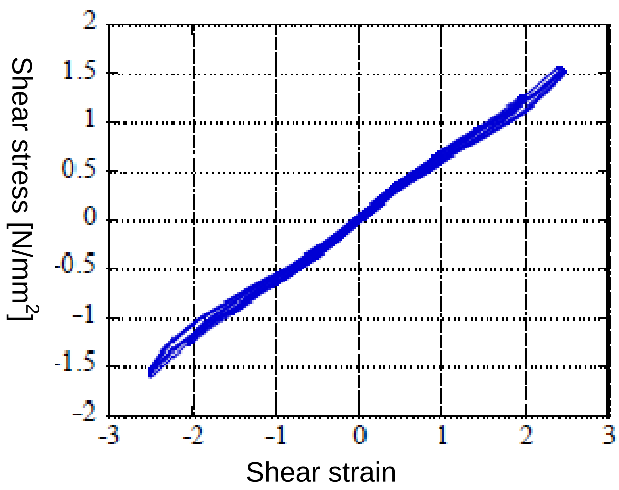
Fig. 2.27 Stress-strain relations of Sine wave NLS at initial temperature 23 °C with 0.2-0.5 [Hz] frequency



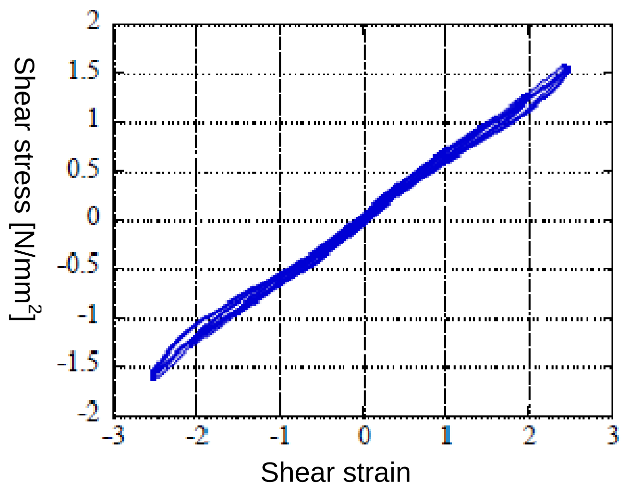
(a) Frequency 0.2 [Hz]



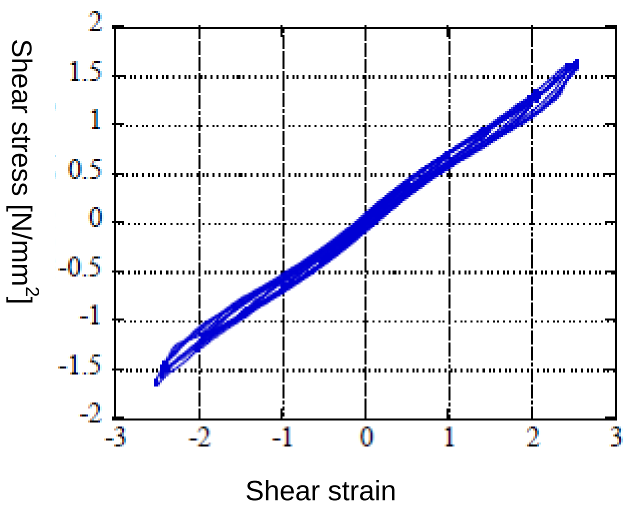
(b) Frequency 0.5 [Hz]



(c) Frequency 1 [Hz]



(d) Frequency 2 [Hz]

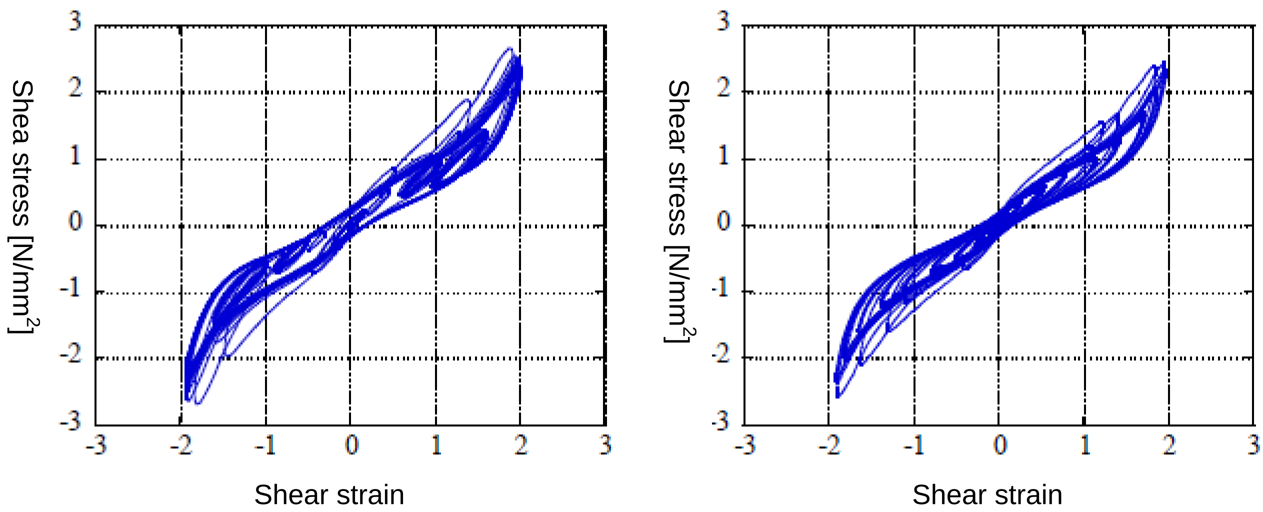


(e) Frequency 5 [Hz]

Fig. 2.28 Stress-strain relations of Sine wave NSS at initial temperature 23 °C with 0.2-5 [Hz] frequency

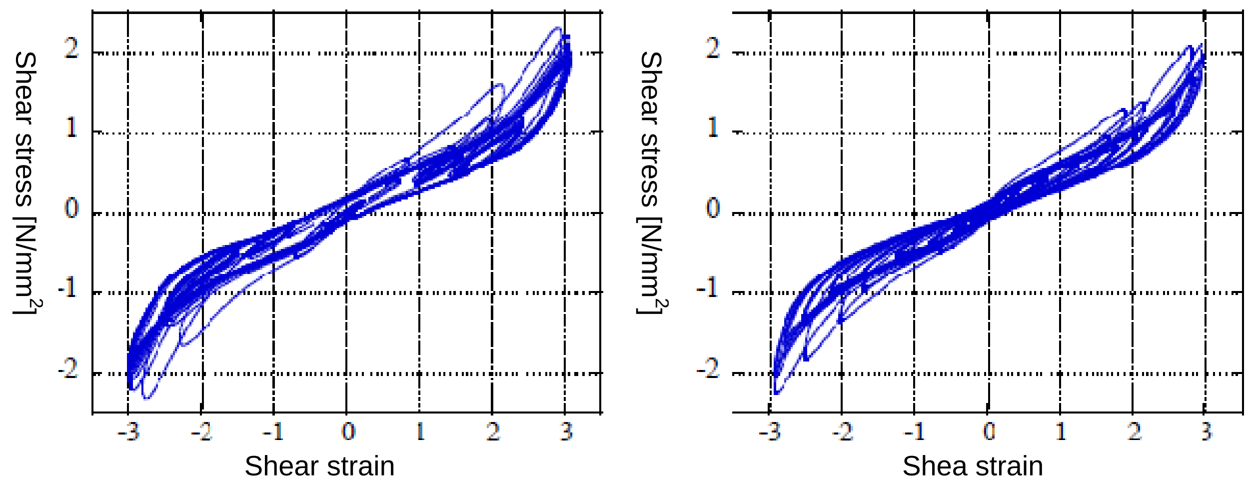
2.5.2 Material tests with other than sine wave

Figs. 2.29, 2.30 and 2.31 show the stress-strain relations for Random waves 1 and 2 at initial temperature 23 °C with 1 [Hz] frequency for NLL, NLS and NSS. These data are valuable to take into account the loading/unloading/reloading in modeling rubber's stress-strain relations.



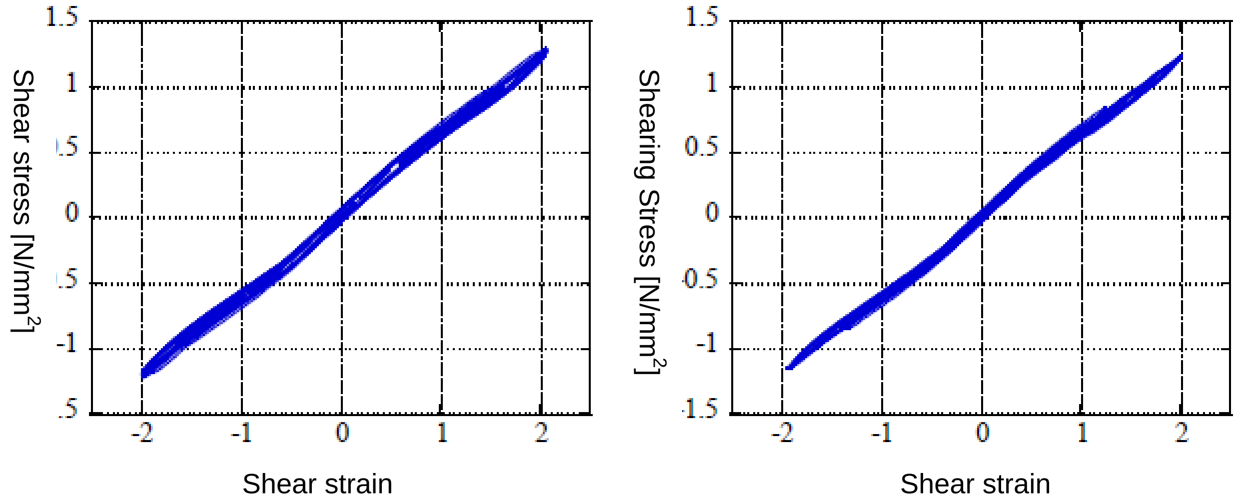
(a) Random wave 1 (b) Random wave 2

Fig. 2.29 Stress-strain relations of Random waves 1 and 2 of NLL at initial temperature 23 °C



(a) Random wave 1 (b) Random wave 2

Fig. 2.30 Stress-strain relations of Random waves 1 and 2 of NLS at initial temperature 23 °C



(a) Random wave 1 (b) Random wave 2

Fig. 2.29 Stress-strains relation of Random waves 1 and 2 of NSS at initial temperature 23 °C

2.5.3 Temperature change in response to loading

Tables 2.9 and 2.11 show the initial temperatures and the highest temperatures for NLL and NLS, respectively. Here, only the temperatures rise of 3 °C or higher are provided in the tables. The temperature changes in NSS were within 3°C. NLL reveal large temperature changes before and after the deformation, but NLS and NSS show only small breadth of rise. In all the materials, the temperature changes tend to large as its amplitude and frequency increase. The rise is not very large with amplitudes of 1-2 mm, but the breadth of rise becomes large for 4 mm amplitude or more.

When loaded in Sine wave, the maximum temperature rises were about 5.6°C for NLL, about 7.6°C for NLS and about 2.3°C for NSS with 5 Hz frequency and 8 mm amplitude (12mm in NLS and 10mm in NSS) in all the materials. For Random wave 1, the temperature rises were about 9.9°C for NLL, about 6.5°C for NLS and about 1.9°C for NSS. For Random wave 2, the temperature rises were about 5.4°C for NLL, about 2.7°C for NLS and about 0.6°C for NSS. Figs. 2.32, 2.33 and 2.34 show waveforms of Sine wave, Random waves 1 and 2 in terms of the displacements at each time step. Figs. 2.35, 2.36 and 2.37 show NLL's temperature changes in response to the loading of Sine wave, Random waves 1 and 2 with 5 Hz frequency and 8 m amplitude. Figs. 2.38, 2.39 and 2.40 show NSS's temperature changes.

From these results, it can be seen that the temperature rise is large in the materials with high hardness and large damping characteristics. Since the loading values for Random waves 1 and 2 are larger than that for Sine wave, it is possible that the excitation waveforms and the number of cycles are influential.

Table 2.9 Initial temperature and highest temperature of NLL
(only temperatures with temperature changes of 3°C or more)

Input displacement	Frequency [Hz]	Amplitude [mm]	Initial temperature [°C]	Highest temperature [°C]
	0.5	8	23.1	26.2
	1	8	23.1	28.1
Sine wave	2	8	24.3	28.7
		6	23.5	26.8
5		8	24.3	29.9
Random wave 1	1	6.3	23.6	33.5
Random wave 2	1	8	22.1	27.5

Table 2.10 Initial temperature and the highest temperature of NLS
(only temperatures with temperature changes of 3°C or more)

Input displacement	Frequency [Hz]	Amplitude [mm]	Initial temperature [°C]	Highest temperature [°C]
	0.5	12	22.5	26.5
		10	21.5	25.3
Sine wave	1	12	23.2	27.8
		8	22.4	25.5
	2	10	22.5	27
Random wave 1		12	22.7	28.4
Random wave 2		8	23,6	27.2

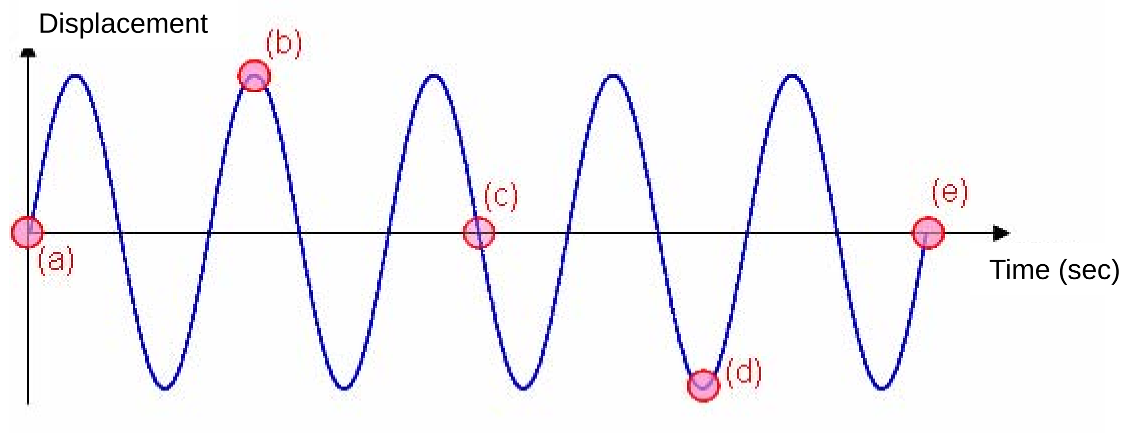


Fig. 2.32 Displacement series in time of Sine wave

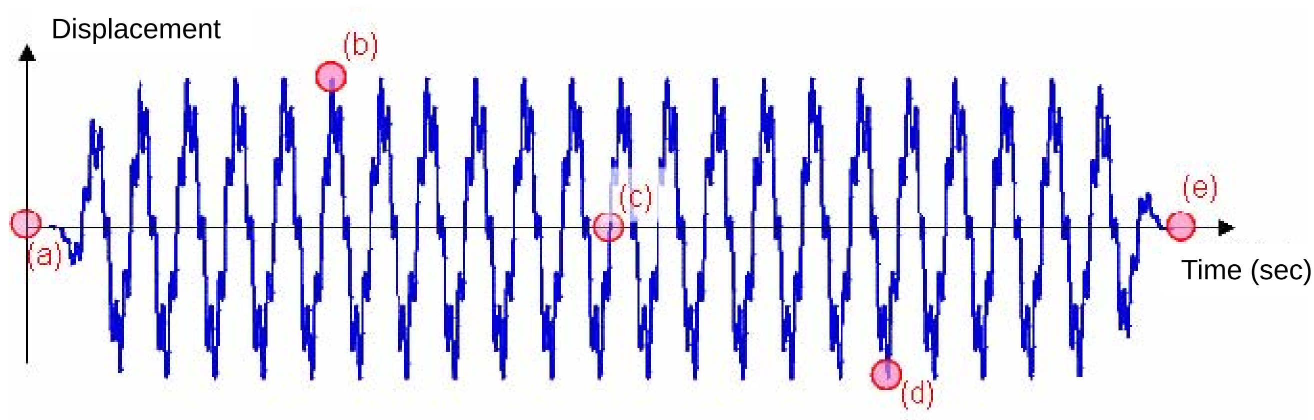


Fig. 2.33 Displacement series in time of Random wave 1

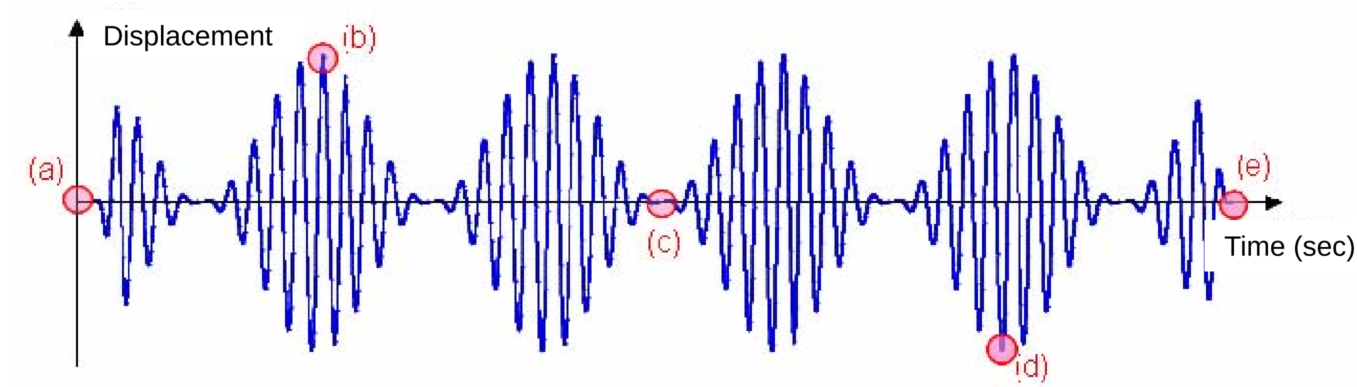
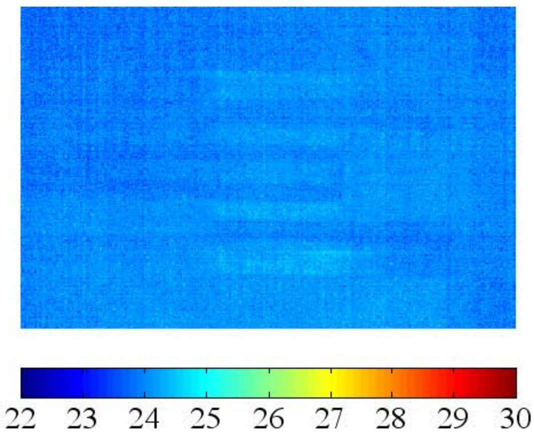
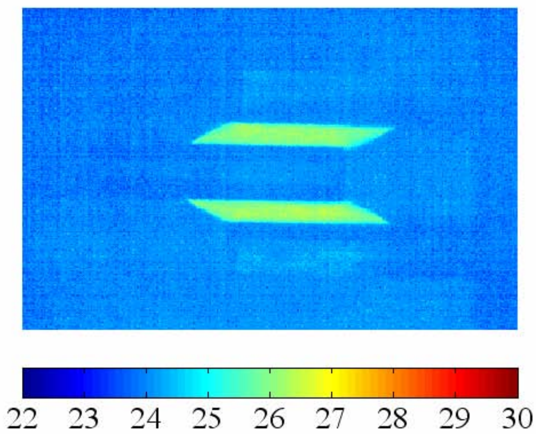


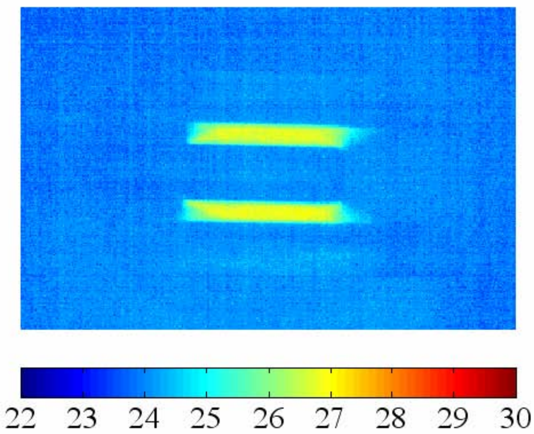
Fig. 2.34 Displacement series in time of Random wave 2



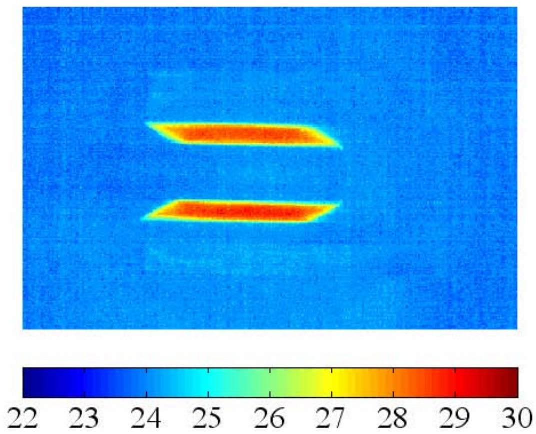
(a) Just after the loading started



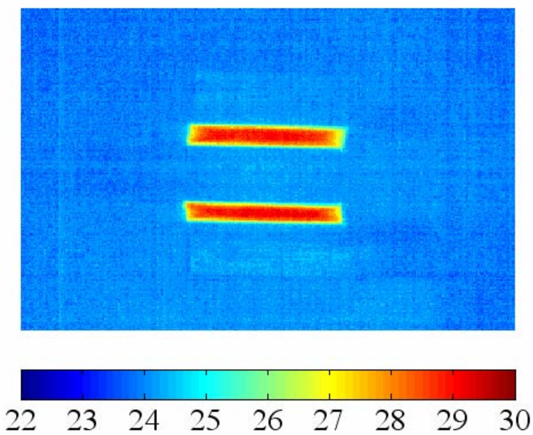
(b) After 0.25 seconds



(c) After 0.5 seconds

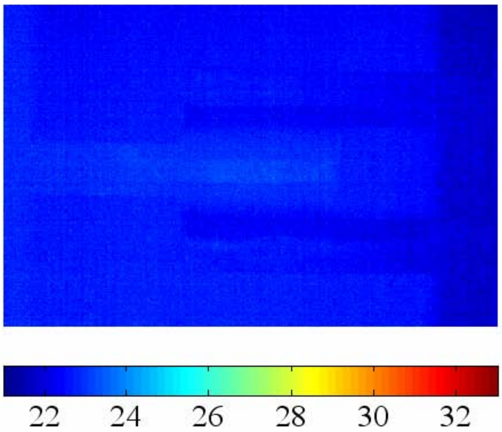


(d) After 0.75 seconds

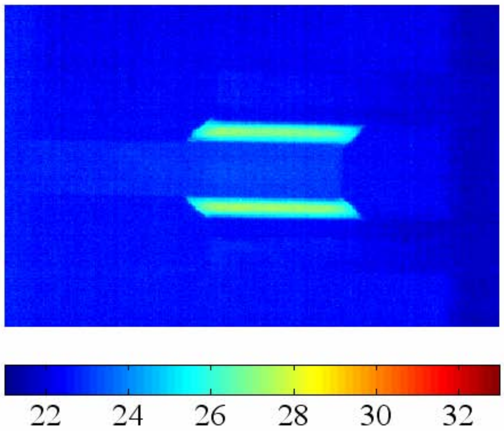


(e) At the end of the test

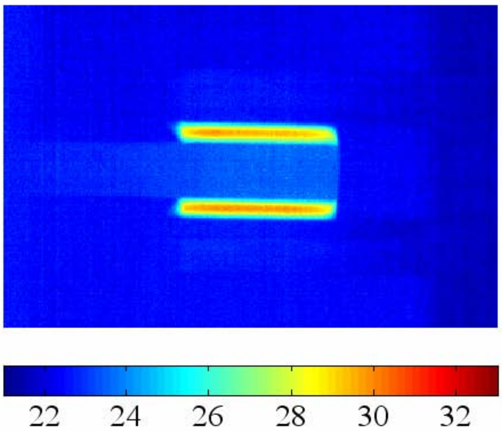
Fig. 2.35 Temperature distributions for Sine wave for NLL at initial temperature 23 °C with 5 Hz frequency and 8 mm amplitude



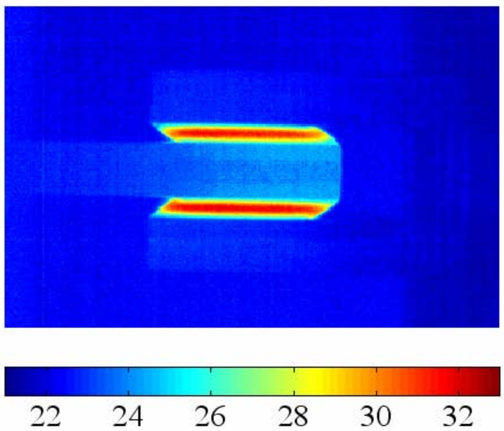
(a) Just after the loading started



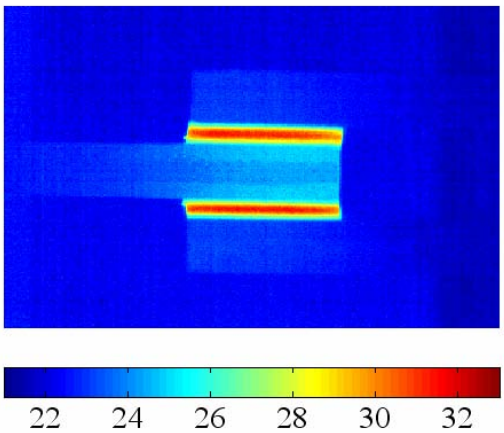
(b) After 6 seconds



(c) After 12 seconds

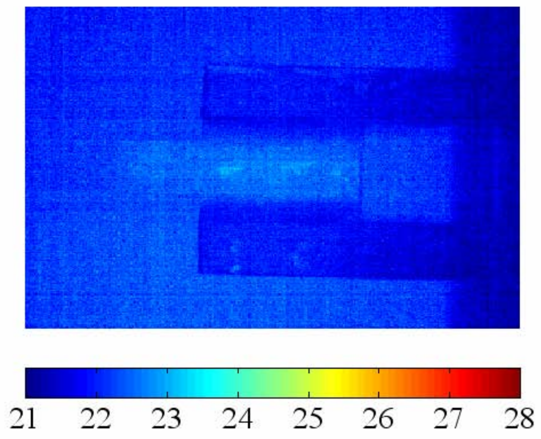


(d) After 18 seconds

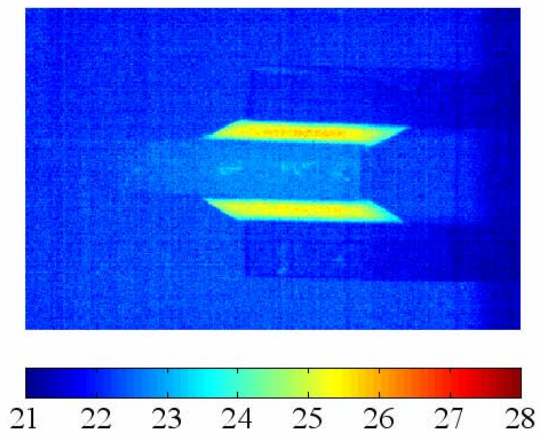


(e) At the end of the test

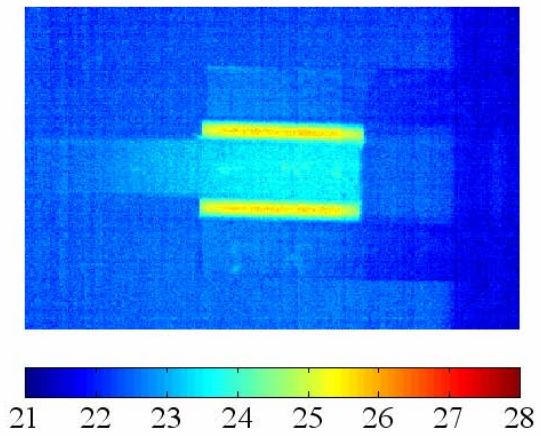
Fig. 2.36 Temperature distributions for Random wave 1 of NLL at initial temperature 23 °C with 1 Hz frequency and 6.3 mm amplitude



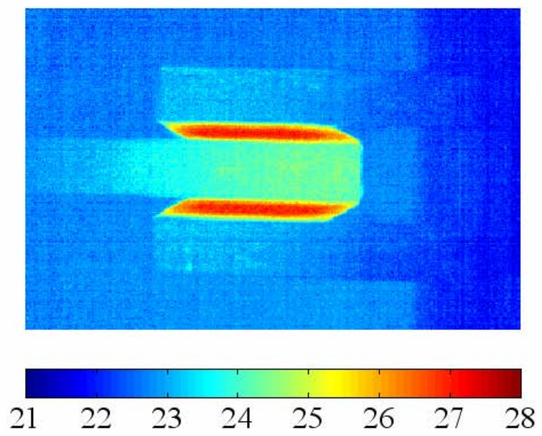
(a) Just after the loading started



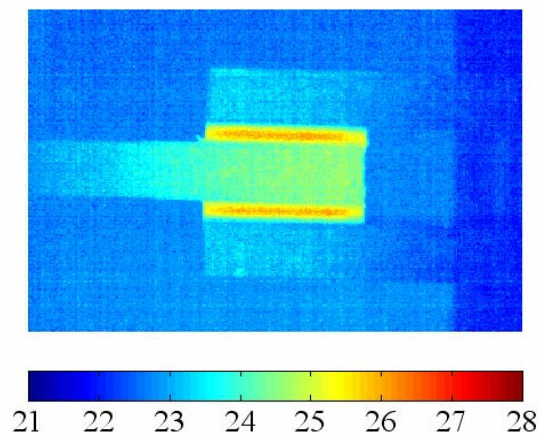
(b) After 10 seconds



(c) After 25 seconds

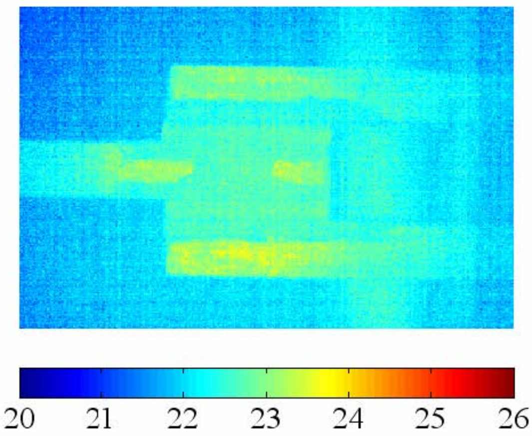


(d) After 40 seconds

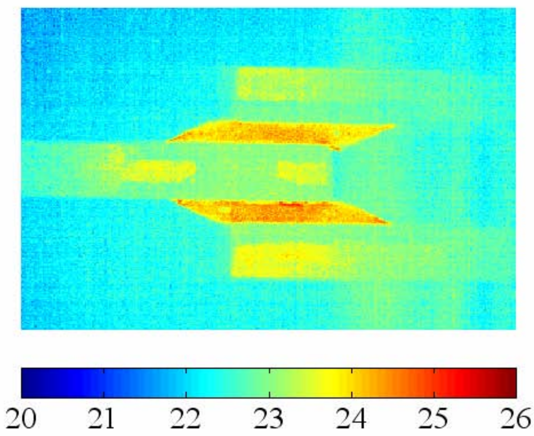


(e) At the end of the test

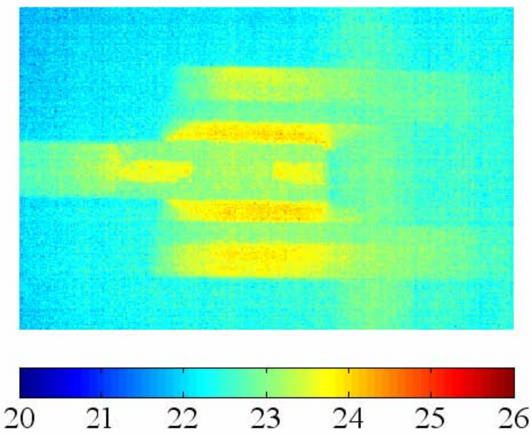
Fig. 2.37 Temperature distributions for Random wave 2 of NL at the initial temperature 23 °C with 1 Hz frequency and 8 mm amplitude



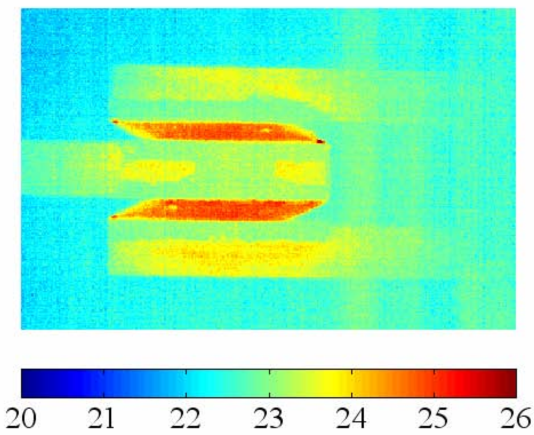
(a) Just after the loading started



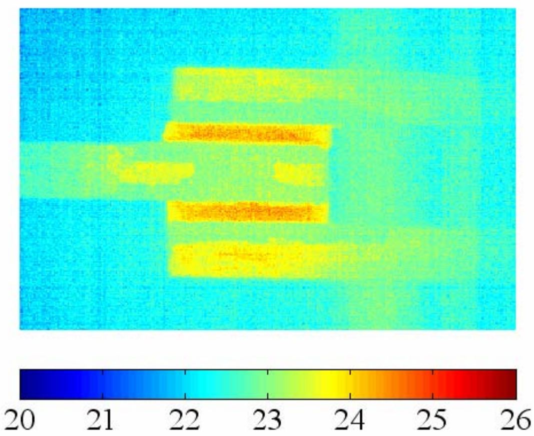
(b) After 0.25 seconds



(b) After 0.5 seconds

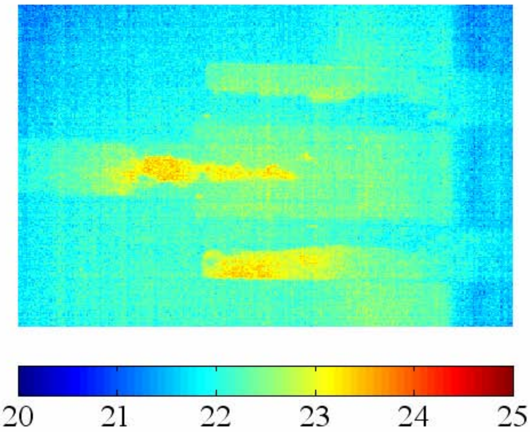


(d) After 0.75 seconds

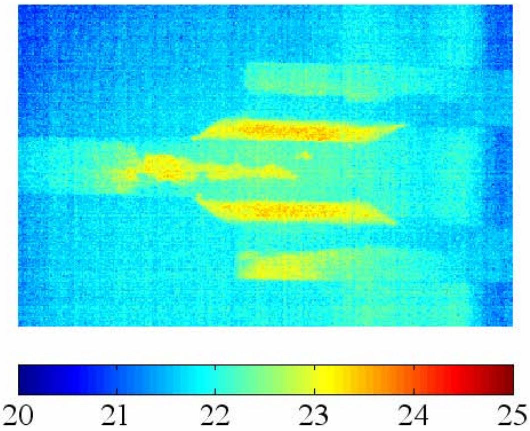


(e) At the end of the test

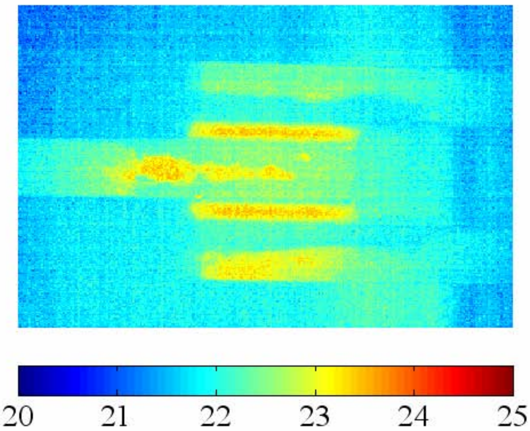
Fig. 2.38 Temperature distributions for sine wave of NSS at initial temperature 23 °C with 5Hz frequency and 10 mm amplitude



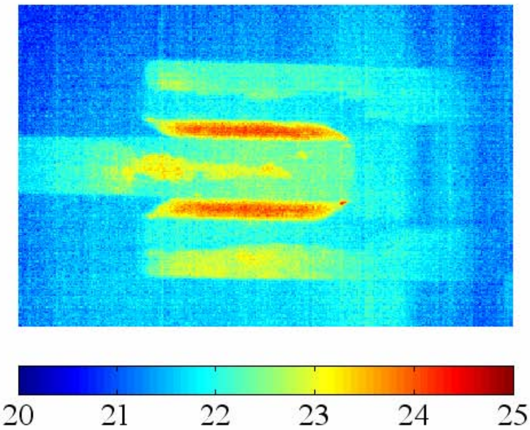
(a) Just after the loading started



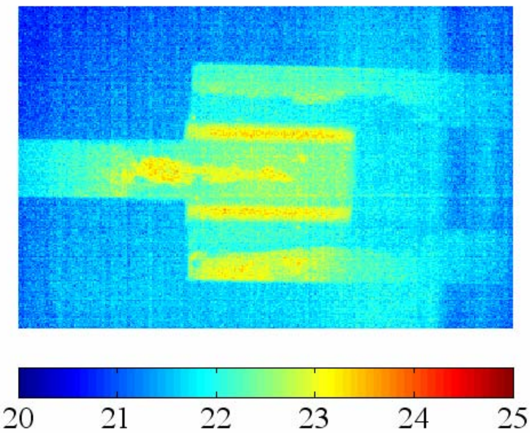
(b) After 6 seconds



(c) After 12 seconds

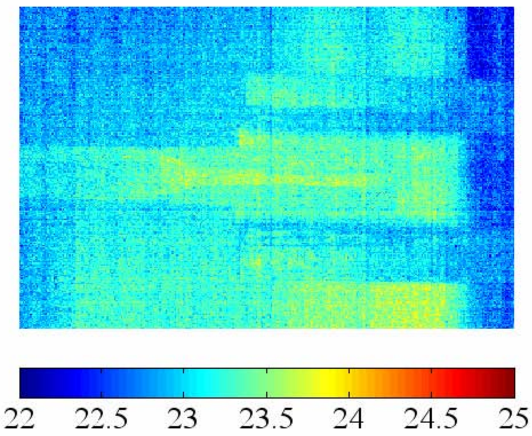


(d) After 18 seconds

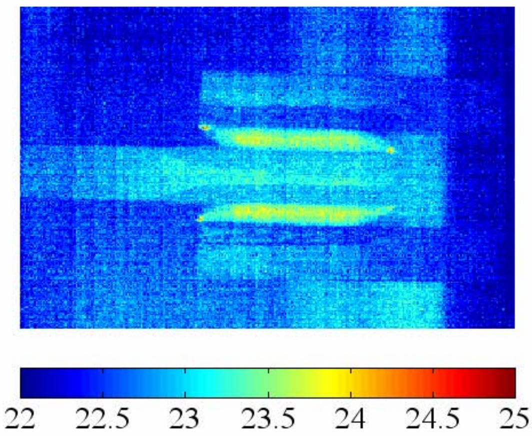


(e) At the end of the test

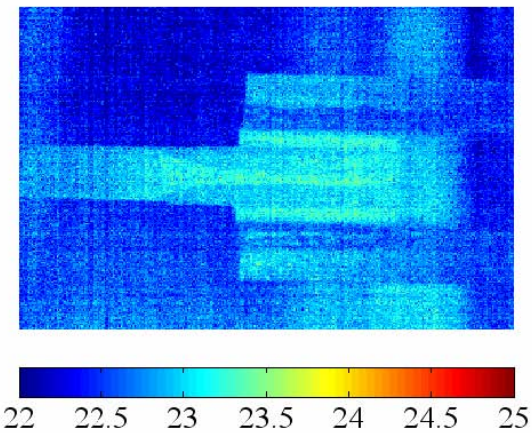
Fig. 2.39 Temperature distributions for Random wave 1 of NSS at initial temperature 23 °C with 1Hz frequency and 6.3 mm amplitude



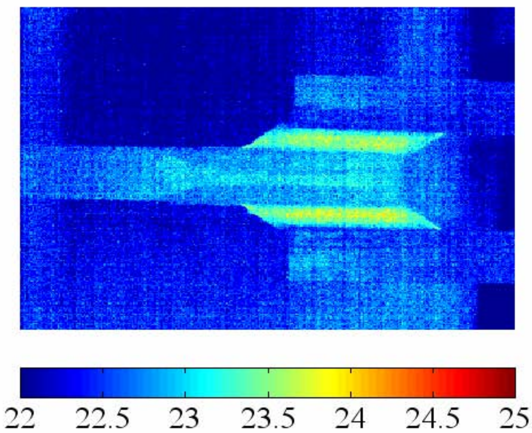
(a) Just after the loading started



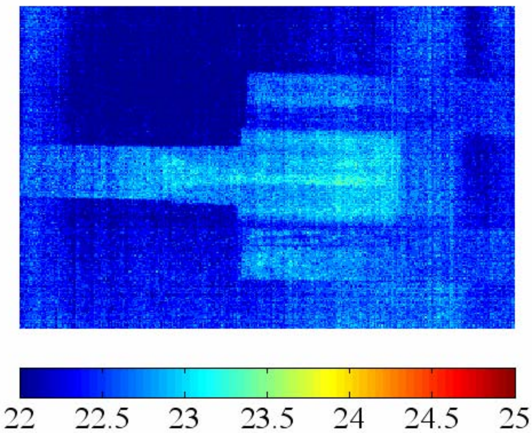
(b) After 10 seconds



(c) After 25 seconds (d)



After 40 seconds



(e) At the end of the test

Fig. 2.40 Temperature distributions for Random wave 2 of NSS at initial temperature 23 °C with 1 Hz frequency and 8 mm amplitude

2.6 Conclusion

In this chapter, we present the rubber material tests at normal temperature. A series of dynamic loading tests were conducted for three kinds of waves at initial temperature of 23 °C with 0.2 ~15 Hz frequencies and 1~12 mm amplitudes.

We demonstrated the relationships between stress and strain by utilizing the data obtained from the tests, compared and examined those results.

The materials with small damping characteristics showed almost elastic behavior in their stress-strain curves, while those with large damping characteristics revealed hardening. Also, the history trajectories of stress-strain curves became large as the loading rates were increased. This is probably due to the fact that rubber molecules cannot follow such high loading rates that their movements freeze. From these results, it can be safely concluded that rubber material behavior depends on excitation frequencies.

To obtain accurate data, it is vital to wait until a specimen is restored to its original state before the next test is started, taking some intervals after a test.

Chapter 5

Rubber material testing under low/high temperature

3.1 Summary

This chapter provides the dynamic loading tests for rubber materials under different temperatures from – 20 °C to +40 °C and reviewed those changes. After describing the testing methods and loading conditions, we study the test results.

3.2 Testing method

We conducted dynamic loading tests for rubber materials by applying a sine wave excitation under low/high temperature. In consideration of the actual usage environment, the initial temperature was set at -20°C or 5°C in the case of low temperature, and 40°C in the case of high temperature. The amplitude prepared for the tests ranges from 1 mm of the infinitesimal wave to 12 mm of the large wave, and the frequency level ranges from 0.2 Hz of the low frequency to 5 Hz of the high frequency. For the infinitesimal wave's amplitude of 1 mm, we also carried out the tests with frequencies of 10 Hz and 15 Hz.

In order to obtain the stable waveform data, the sine wave of five cycles was prepared. The data of the displacement and the acceleration were obtained from the vibration table, while the loading data applied to rubber materials were obtained from the load cell. The temperatures were measured by the infrared camera placed on the vibration table.

In the loading test with the initial temperature of -20 °C, the specimen was cooled down in a freezer. In this case, the specimen was covered by a plastic bag to prevent it from being wet. Also, a cold insulator was applied to the specimen so as not to increase the temperature during the installment, and is removed when the test was started. However, since a large amount of heat outflow is recognized in the actual testing, and the low temperature could not be kept constant, this case was excluded from the loading patterns in the series of testing. For reference, a photo of the freezer and its specification are presented in Figure 3.1 and Table 3.1, respectively. The tests cases with the specimens at the initial temperature of 5 °C were carried out after the room temperature was decreased and the specimen temperature was reduced around 5°C, when the ambient air had a low temperature.

On the other hand, in the loading tests at the initial temperature of 40°C, we covered a specimen by a foam carton and sent hot-air to it in order to adjust the initial temperature. In the loading tests with the initial temperature of 5°C or 40°C, we conducted the tests with the interval of about 5 minutes so that the specimen is restored to its original temperature in order to equalize the loading condition. The loading patterns are indicated in Table 3.2.

Figure 3.1 Freezer

Table 3.1 Freezer specification

Product name	Bio-Medical Freezer
Product number	MDF-236
Freezing performance	Achievable inside temperature in the central area of the freezer: 35°C (Ambient temperature: 35°C, no load)
Control range of temperature inside	20-35 °C
Rated electrical power consumption of electric machinery	115 W/130 W
Rated current of electric machinery	1.5 A/1.3 A
Maximum power consumption	151 W/172 W
Maximum total power current	1.8 A/1.7 A
Maximum heat radiation amount	544 KJ/h/ 619 KJ/h
Usage environment	Temperature: 5-35°C Humidity: 80% RH or lower

Table 3.2 Loading patterns of material tests under low/high temperatures

Frequency / Temperature	0.2 Hz	0.5 Hz	1 Hz	2 Hz	5 Hz	10 Hz	15 Hz
-20°C	N/A N/A		N/A	N/A N/A	N/A N/A		
5°C	YES	YES	YES YES	YES	YES	YES	
4°0C	YES	YES	YES YES	YES	YES	YES	