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International
Journal
Of Modern Engineering Research (IJMER)

Low temperature mechanical behavior of high damping rubber material

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ABSTRACT:*High damping rubber material (HDR) has many useful applications in engineering, cause of his special properties. Nowadays many important products that meet high requirements are made of HDR, such as tires, seals, vibration mounts, bearings for bridges and for seismic isolation of structures. In order to investigate the mechanical behavior of HDR, especially at low temperatures. The experimental work was conducted on small specimens in the double-lap shear configuration that retained stability during reversed cyclical loading. The experimental scheme is comprised of three types of tests at three different temperatures (-30^{o}C, -10^{o}C, and 23^{o}C): multi-step relaxation (MSR) tests, simple shear (SS) tests, and simple relaxation (SR) tests. The aim of conducting MSR, SS, and SR tests is to identify the equilibrium behavior, instantaneous behavior; and nonlinear viscosity behavior of HDR, respectively, at the different temperatures. Experiemental results indicate that the Mullins effect increases together with the decrease of test temperature and the temperature dependence of the Mullins effect is very pronounced. In addition, from SS test and MSR test results, we also observe that the test temperature influences both the equilibrium and instantaneous stress responses. This influence is significant and necessary to include in the design process. Finally, SR test results show that the stress relaxation in loading and unloading of HDR remarkably depends on the test temperature and the strain amplitude.*
KEY WORDS:*Temperature-dependent, Viscosity behavior, High damping rubber, Stress-softening*

Date of Submission: 18-12-2018 Date of acceptance: 31-12-2018

I. INTRODUCTION

High damping rubber material (HDR) has many useful applications in engineering, cause of its special properties. Nowadays many important products that meet high requirements are made of HDR, such as tires, seals, vibration mounts, bearings for bridges and for seismic isolation of structures. A few researches have been conducted to investigate the temperature effects on mechanical properties of HDR. Yoshida et al. [1] have studied thermal-mechanical behavior of HDR, although they did not consider the behavior of DHR at low temperatures. Imai et al. [2] pointed out that temperature dependence on the shear stress-strain responses of HDR was appeared more significantly than in the lead rubber and the natural rubber. To better understand the material behavior, this paper presents an experimental investigation of temperature dependence of HDR at the low temperatures.

II. EXPERIMENT

The experimental work was conducted on small specimens in the double-lap shear configuration (Fig.1) that retained stability during reversed cyclical loading. There were two HDR pads in the specimen each being, nominally, 25x25x5 mm. All specimens were preloaded before carrying out the actual tests and kept in the test temperature over 1 hour before the preloading. The time interval between the preloading and the actual tests were kept in the test temperature.

The experimental scheme is comprised of three types of tests at three different temperatures (23^{o}C, -10^{o}C, and -30^{o}C): multi-step relaxation (MSR) tests, simple shear (SS) tests, and simple relaxation (SR) tests. The aim of conducting MSR, SS, and SR tests is to identify the equilibrium behavior, rate-dependent behavior; and nonlinear viscosity behavior of HDR, respectively, at the different temperatures.

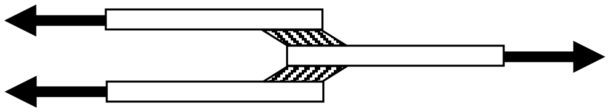

Figure 1: The double-lap shearspecimen
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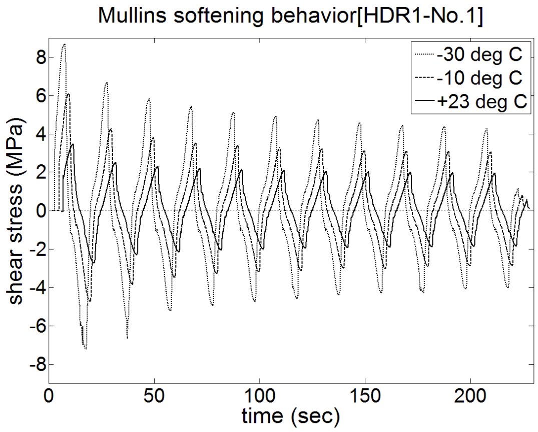
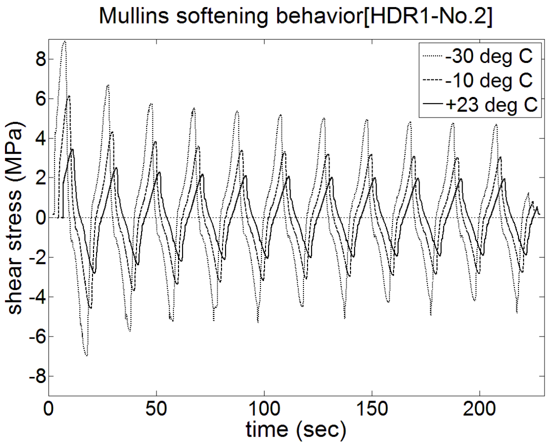
III. EXPERIMENT RESULTS AND DISCUSSION

3.1Softening behavior

Virgin rubber typically exhibits a softening phenomenon, known as Mullins' effect in its first loading cycle. Due to presence of this typical behavior, the first cycle of a stress-strain curve differs significantly from the shape of the subsequent cycles [3]. In order to remove the Mullins softening behavior from other inelastic phenomena, all specimens were preloaded before the actual tests. In the current work, the preloading was done by treating 11 cycles of sinusoidal loading at 1.75 strain and 0.05 Hz until a stable state of the stress-strain response is achieved i.e. that no further softening occurs.



(a)



(b)

Figure 2: Preloading test on HDR1 specimens at the different temperatures ; (a) HDR1-No.1, (b) HDR1-No.2

Fig. 2 (a), and (b) present the typical shear stress responses obtained from pre-loading tests on two HDR specimens (HDR1-No.1 and HDR1-No.2) at room and low temperatures. The softening behavior is much larger at low temperatures. This implies that the Mullins effect increase with the decrease of the test temperature.

3.2Equilibrium behavior

Due to the inherent viscosity property in rubber material, it is practically impossible to identity the equilibrium response by applying infinitely slow loading rate. Hence, the MSR test was employed with the primary objective to identify the equilibrium response of HDR. The similar approach was also employed by Amin et al. [4]; Bergstrom and Boyce [5]; Lion [6,7] to identify the equilibrium response of rubber materials. The strain history applied in MSR test is presented in Fig. 3, where a number of relaxtion periods of 20 min during which the applied strain is held constant are inserted in loading and unloading at a constant strain rate of 5.5/s. The convergence of the stress response is identified in an asymptotic sense [6]. The shear stress-strain relationship in the equilibrium state can be obtained by connecting all the asymptotocally converged stress values at each strain level.

Fig. 4 shows the results of MSR tests at the different temperatures. The hide lines present the equilibrium responses obtained from MSR tests. Comparing the equilibrium responses at the different temperatures, there is a big difference. This seem that the quilibrium response of HDR significantly depends on the test temperature.

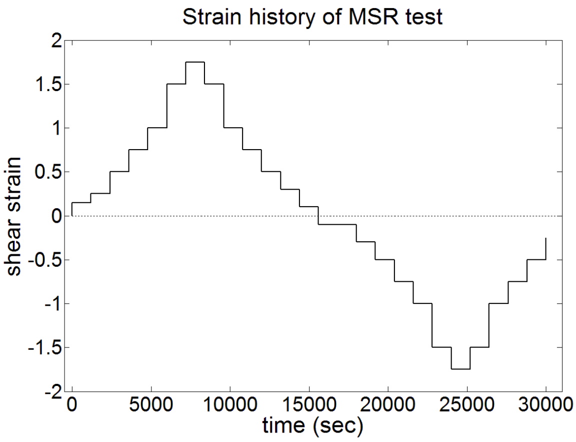


Figure 3: Strain histories applied in MSR tests

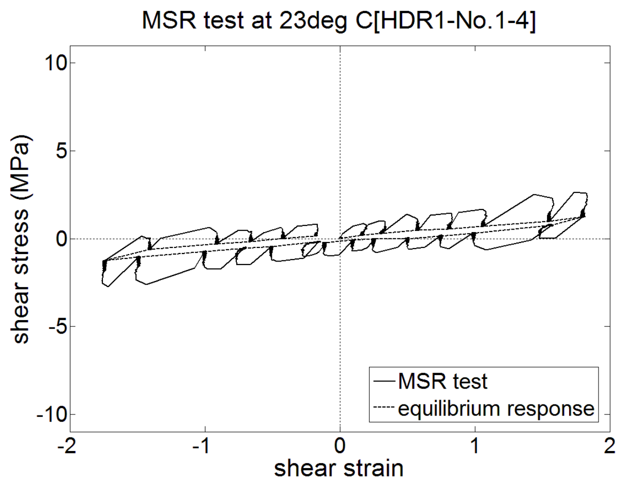
3.3Viscosity behavior

SR tests were carried out to study the viscosity behavior of HDR. A series of SR tests at different strain levels and different temperatures were conducted. Figs.5 show the shear stress histories obtained form SR tests conducted at the three different temperatures with three shear strain levels of 100%, 150%, and 175%, the strain rate of the tests is 5.5/s.

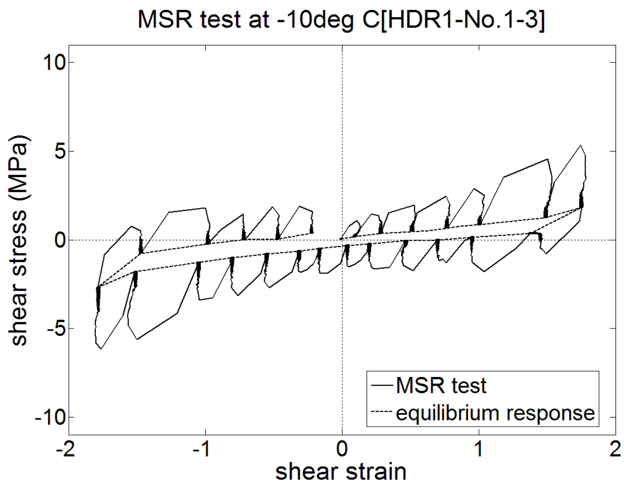
From Fig.5 (a) to (c), the stress relaxation is very different at different temperatures. This stress is much lagrer at low temperatures. It implies that the viscosity behavior of HDR increases when temperature decreases.

3.4Rate-dependent behavior

SS tests were carried out with three strain rates of 0.5/sec, 1.5/sec, 5.5/sec. In order to get more information at low temperatures, SS tests were also conducted at -40^{o}C. Fig. 6 presents the results of SS tests at different temperatures. The results show that the stiffness and damping of HDR is larger at lower temperatures. The trend of increasing the shear stress responses with decrease of temperatures is clearly evident.



(a)



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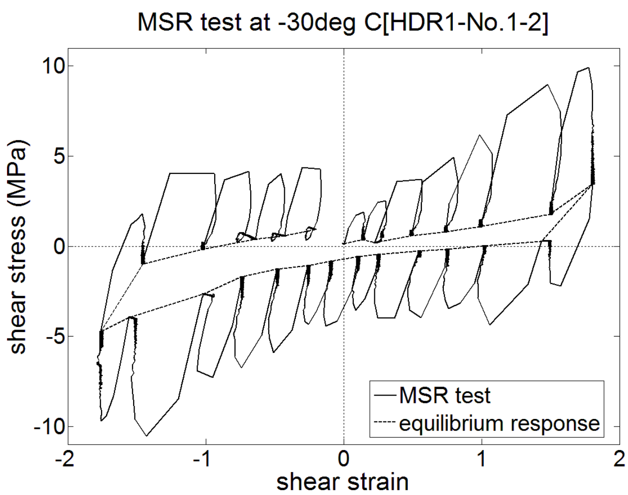
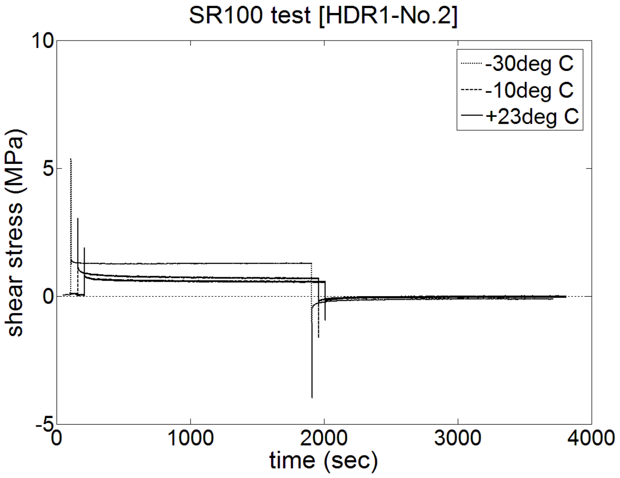


(c)

Figure 4: MSR test results obtained at (a) +23^{o}C, (b) -10^{o}C, and (c) -30^{o}C



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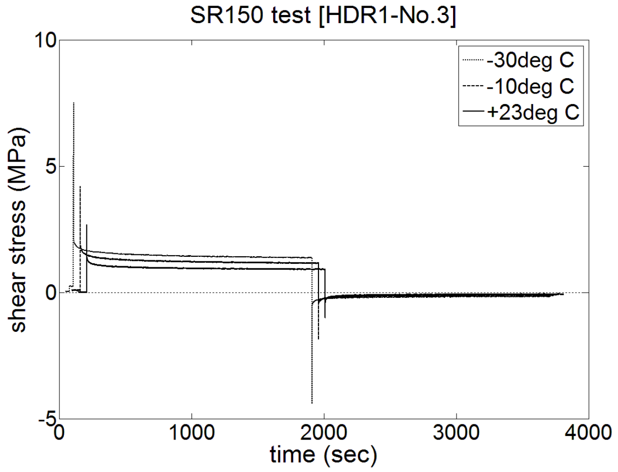

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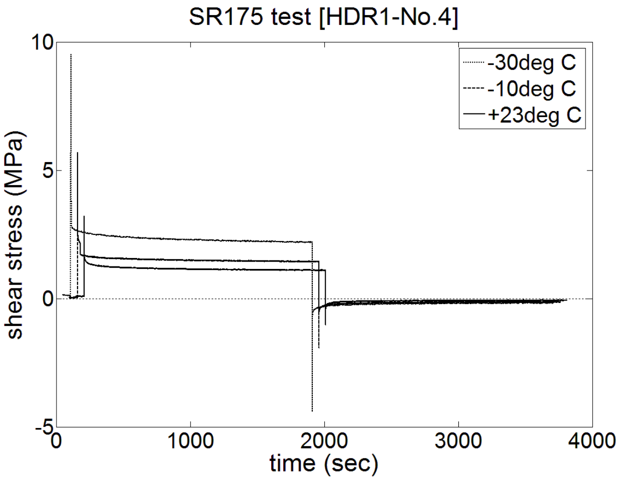
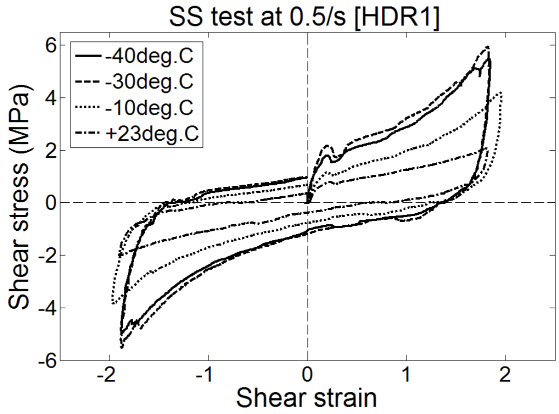


(c)

Figure 5:Shear stress histories obtained from SR tests at different temperatures and at different strain levels; (a) at 100% strain level, (b) 150% strain level, and (c) 175% strain level.



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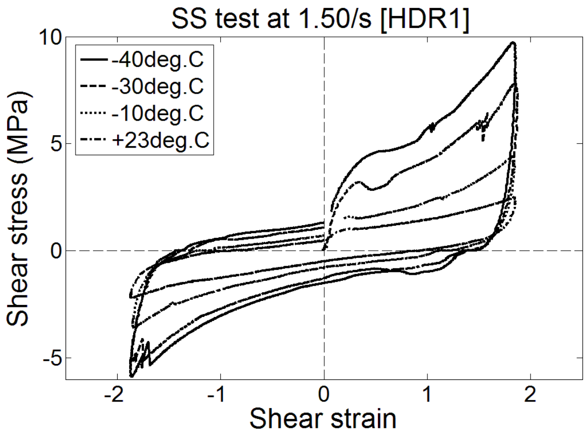

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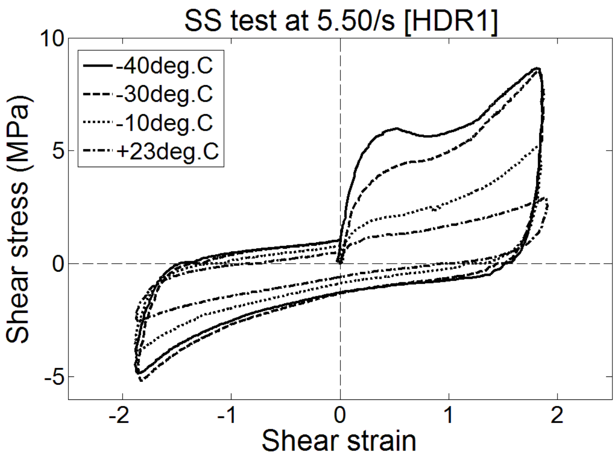

(c)

Figure 6: SS tests at strain rate of (a) 0.5/sec, (b) 1.50/sec, and (c) 5.50/sec

IV. CONCLUDING REMARKS

Experiemental results indicate that the Mullins effect increases together with the decrease of test temperature and the temperature dependence of the Mullins effect is very pronounced. In addition, from SS test and MSR test results, we also observe that the test temperature influences both the equilibrium and instantaneous stress responses. This influence is significant and necessary to include in the design process. Finally, SR test results show that the stress relaxation in loading and unloading of HDR remarkably depends on the test temperature and the strain amplitude. These experimental data is useful for the developing of temperature-dependent mechanical material models for high damping rubber bearings.

ACKNOWLEDGEMENTS

The experimental works were conducted by utilizing the laboratory facilities and bearings-specimens provided by Japan Rubber Bearing Association. Author indeed gratefully acknowledge the kind cooperation extended by them in performing the tests. This work was supported by JSPS KAKENHI（Grants-in-Aid for Scientific Research）Grant Number 26289140 and Prof. Okui in Saitama university, Japan.

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Nguyen Anh Dung" Low temperature mechanical behavior of high damping rubber material" International Journal of Modern Engineering Research (IJMER), vol. 08, no. 10, 2018, pp 23-29