

## Damping Properties and Transmission Loss of Polyurethane. II. PU Layer and Copolymer Effect

Kwan Han Yoon\*, Ji Gon Kim, and Dae Suk Bang

School of Advanced Materials and System Engineering, Kumoh National Institute of Technology, Gumi 730-701, Korea  
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**Abstract:** Polyurethane (PU) layer and copolymer consisted of the different molecular weights (1000 and 2000 g/mol) of poly(propylene glycol) (PPG) were prepared. The damping and mechanical properties of these materials were compared with PU1000 made by PPG having the molecular weight of 1000 g/mol. The optimum composition of PU2000 used for PU layer and copolymer was diphenylmethane diisocyanate (MDI)/propylene glycol (PPG)/butanediol (BD) (1/0.3/0.7) based on the damping and mechanical properties. The damping peak of PU copolymer was higher than those of PU layer and PU1000 in low temperature range (-30-10 °C). For application in noise reduction, the transmission loss of the mechanical vibration through solid structure was measured. PU layer and copolymer were used as a damping layer. The transmission loss of PU copolymer was more effective than those of PU layer and PU1000 in the experimental frequency range.

**Keywords:** Polyurethane, PU layer, Copolymer, Damping, Transmission loss

### Introduction

Polymers[1-3] are often used in sound and vibration damping areas. In general, one of the most important properties of polymers in these applications is the glass transition. At the glass transition, a polymer is the most efficient in converting sound and mechanical vibration energy into heat that results in absorption.

Polyurethanes (PU)[4-10] are particularly attractive for the study of the effect of chemical structure on damping since it is possible to change their glass transitions over a wide range of temperature. This corresponds to a damping peak location that spans more than 10 decades of frequency. In addition, changes in polyurethane structure can be used to produce a transition that can vary from narrow to broad. Polyurethanes are alternating block copolymers made of soft segments derived from polyester or polyether diols and hard segments which come from the diisocyanate and diol chain extender. Since the soft and hard segments are chemically dissimilar, they tend to be incompatible and separate into different phases.

In our previous paper[11], we studied the damping and transmission loss of polyurethane with the soft and hard segment compositions. Due to the mutual relation between the damping efficiency and the mechanical properties, it was difficult to find the optimum composition of soft and hard segments. In terms of the transmission, however, polyurethane (PU1000, made by poly(propylene glycol) (PPG) having the molecular weight of 1000 g/mol) consisted of the compositions of diphenylmethane diisocyanate (MDI)/PPG/butanediol (BD) (1.1/0.5/0.5) was more effective than other compositions.

In this paper, we tried to improve the transmission loss in lower frequency range than the previous one (PU1000)

prepared with PPG1000. So we prepared PU2000 made by PPG having the molecular weight of 2000 g/mol. The damping and transmission loss of PU layer consisted of PU1000 and PU2000 was studied. Also its copolymer was prepared to compare with PU layer.

### Experimental

#### Materials

Poly(propylene glycol) (PPG), having molecular weights of 1000 and 2000 g/mol was obtained from Korea Polyol Co., Korea. 4,4'-Diphenylmethane diisocyanate (crude MDI, having functionality of 2.54) was obtained from Korea BASF Urethane, Korea. 1,4-Butanediol (BD), chain extender, was obtained from Junsei Chemical Co. Ltd., Japan.

#### Preparation of Prepolymers

In a four-necked flask equipped with a mechanical stirrer, thermometer, nitrogen inlet and outlet, a predetermined quantity of MDI was added. The desired amount of PPG was added to the crude MDI. The reactants were stirred vigorously for 15 min at room temperature, and reacted and degassed at 75 °C for 15 min in a vacuum oven. After that, the reactants were stirred again vigorously at room temperature, and then degassed for additional 15 min. After the 2-3 repetitions of the above methods, the liquid phase polyurethane prepolymer was obtained. In order to prepare PU precopolymer, PPG having different molecular weights were added together to MDI initially and the reaction was progressed according to the above mentioned procedure.

#### Preparation of Elastomers

The required amounts of PU prepolymers and BD were mixed and stirred vigorously, degassed, and poured into a heated sheet mold and cured at 100 °C for 6 h in a hot oven.

\*Corresponding author: khyoon@kumoh.ac.kr

The sheet of elastomers produced was 12 × 45 × 3.2 mm in size. In order to make PU layer, PU2000 prepolymer was poured onto the surface of PU1000 elastomer made in advance and solidified with the above procedure. The solidified polyurethanes were demolded and maintained for 18 h in hot oven. All the samples were postcured at room temperature for 7 days prior to testing. The compositions of MDI, PPG, and BD of the samples are listed in Table 1.

**Dynamic Mechanical Analysis**

The dynamic storage and loss moduli were measured using a dynamic mechanical analysis (DMA) (DuPont DMA 983). The measurements were made at a frequency of  $\omega = 1$  Hz in the temperature range of -50-150 °C at a heating rate of 5 °C/min.

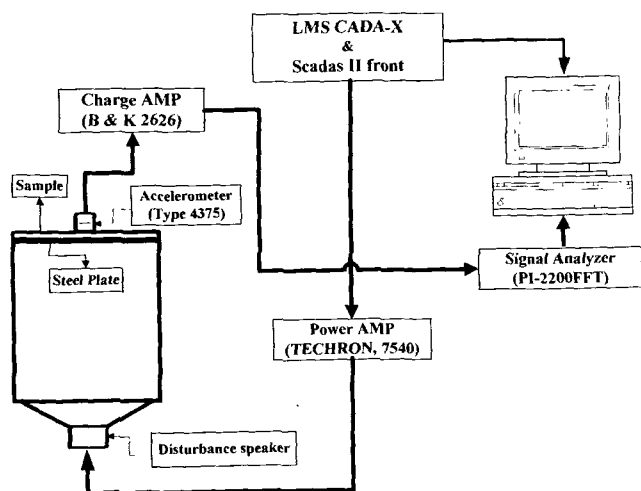
**Mechanical Properties**

The tensile properties, such as tensile strength at yield and elongation at break were measured using an Instron model 4467 universal instrument. Measurements were made at room temperature at a constant crosshead speed of 50 mm/min. Data were taken as an average of at least five measurements. The hardness of samples was measured using hardness tester (GS-710N Shore A type, Tecklok).

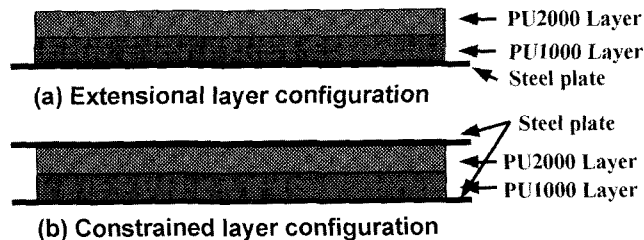
**Table 1.** Molar compositions of the samples

Material	PU1000			PU2000				
	MDI	PPG	BD	MDI	PPG	BD		
Mw (g/mol)	250	1000	90	250	2000	90		
Composition (mol)	1.1	0.5	0.5	1.1	0.3	0.4	0.7	0.6
Content (wt%)	0, 25, 50, 75, 100			0, 25, 50, 75, 100				
NCO/OH <sup>a)</sup>	1.1/1.0			1.1/1.0				

<sup>a)</sup>OH consists of PPG and BD.



**Figure 1.** Acoustic apparatus for transmission loss.



**Figure 2.** Test specimen for dynamic mechanical analysis and acoustic apparatus.

**Transmission Loss**

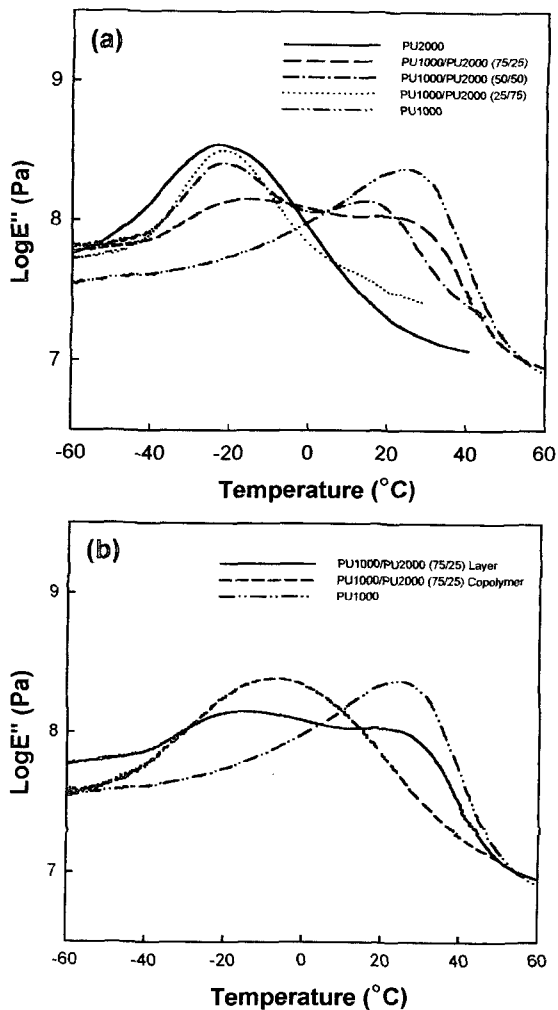
In order to know the effect of PU layer and copolymer on transmission loss through solid structure, an apparatus shown in Figure 1 was used. Vibration source was disturbance speaker controlled from sound source controller, which gives the frequency range of 1 Hz-5 kHz. The signal detected by piezoelectricity (PZT) was analyzed. All the experimental runs were measured at -10 °C, and data were taken as average of 100 measurements. All specimen used in acoustic experiment were 350 × 250 × 8 mm in size, and made as two types shown in Figure 2.

**Results and Discussion**

**Damping Properties**

Figure 3(a) shows the loss modulus of PU layer which was prepared with the content of PU1000 and PU2000. The composition of PU2000 was MDI/PPG/BD (1.1/0.3/0.7), and the reason for choosing this composition will be explained in part of the mechanical properties. We expected that the damping peak of PU layer can be broadened in low temperature range because PU2000 having the soft segment of high molecular weight, PU2000 was used as a layer with PU1000. The increase of damping peak in low temperature range indicates the increase of transmission loss in lower frequency range. It must be noted that a decade of frequency increase is equivalent to an increase in temperature of approximately 6-7 °C. As expected, the damping peaks of PU layer having compositions of PU1000/PU2000 (75/25) and (50/50) were broader than that of PU1000 and higher in low temperature range (below 10 °C) even though the peak height in high temperature range (above 10 °C) was decreased. In order to absorb the vibration energy through solid structure, the damping efficiency corresponding to the area below the modulus and temperature curve should be large. So PU layer having composition of PU1000/PU2000 (75/25) may be effective in terms of damping.

In order to compare the damping efficiency between PU layer and copolymer, the loss modulus of PU copolymer having the same composition with PU layer was measured and shown in Figure 3(b). The reason for choosing this copolymer composition will be also explained in mechanical



**Figure 3.** Loss modulus curves of (a) PU layers with the content of PU2000 and (b) PU layer and copolymer having the composition of PU1000/PU2000 (75/25).

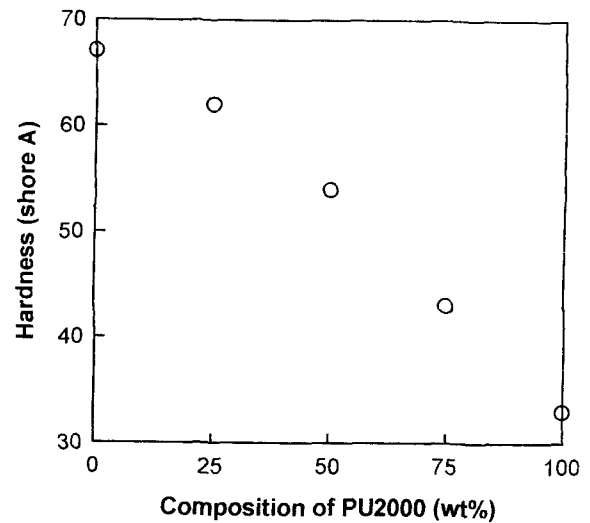
properties. The damping peak of PU copolymer was shifted to lower temperature due to the increase of soft segment, but the height of peak as well as peak area were not changed in comparison with PU1000. However, the damping peak of PU copolymer at low temperature range ( $-30$ – $10$   $^{\circ}\text{C}$ ) was high in comparison with PU layer and PU1000. It indicates that the transmission loss of PU copolymer may be effective in low frequency range compared with PU layer and PU1000.

### Mechanical Properties

Table 2 shows the hardness (Shore A), tensile strength at yield, initial modulus at 0.2 % elongation, and elongation at break with the content of BD for PU2000. The mechanical properties of PU2000 were found to increase continuously with increasing BD contents. According to Petrovic *et al.* [12], the strength of elastomer is related to the relaxation time of mobile chains. Smith also found that hard segments

**Table 2.** Mechanical properties of polyurethane

PU2000	Tensile stress (kg/cm <sup>2</sup> )	Modulus (kg/cm <sup>2</sup> )	Elongation at break (%)	Hardness (shore A)
BD				
0.4	5	5	50	42
0.5	13	9	56	51
0.6	12	13	70	61
0.7	25	39	82	63
PU1000	38	46	144	67



**Figure 4.** Hardness (shore A) of PU copolymer with the content of PU2000.

in segmented polyurethane were highly effective sources of strength. In segmented polyurethane, BD acts as a hard segment. As shown in Table 2, the mechanical properties of PU1000 containing BD0.5 was superior to PU2000 even though the content of hard segment, BD, was increased in PU2000 composition. It results from the difference of the molecular weight of PPG used in this work. In our previous work, we considered that the hardness of polyurethane to be used as acoustic materials should be more than 60. The composition of PU2000 satisfying that condition was MDI/PPG/BD (1.1/0.3/0.7), which was thus used in PU layer and PU copolymer.

Figure 4 shows the hardness of PU copolymer with the content of PU2000. The hardness of PU copolymer was decreased linearly with the content of PU2000. It results from the increase of soft segment because PPG2000 has more soft segments than PPG1000. So the composition of PU copolymer satisfying the hardness was PU1000/PU2000 (75/25).

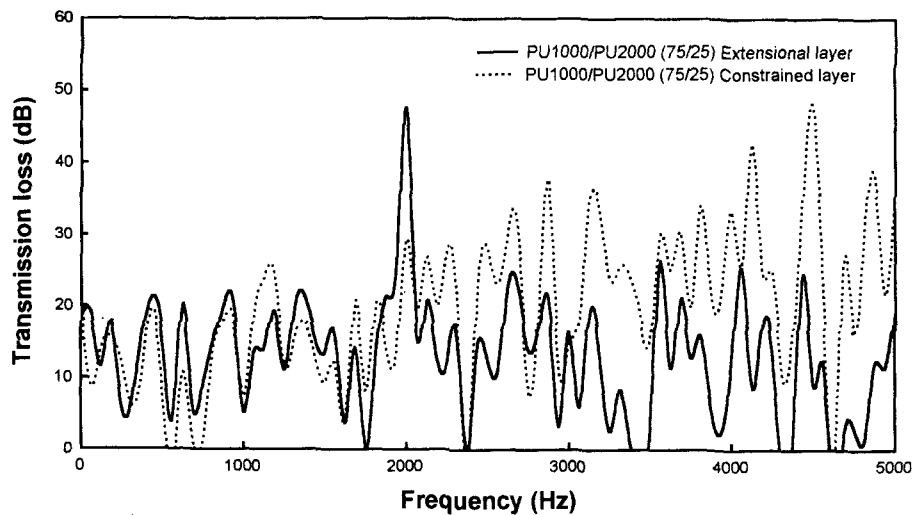
### Transmission Loss

The damping and mechanical properties of PU layer and

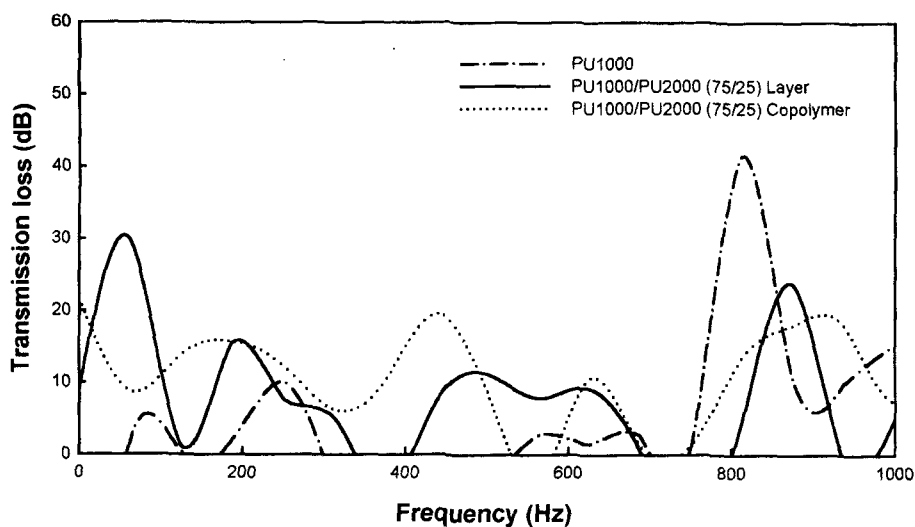
copolymer were discussed. In order to absorb the mechanical vibration energy through the solid structures, polymers coated on the solid surface should have the higher damping efficiency. As before mentioned, there is trade off between the damping and mechanical properties. In terms of damping shown in Figure 3(a), PU layers having compositions of PU1000/PU2000 (75/25) and (50/50) was considerable. In terms of hardness, PU1000/PU2000 (75/25) was higher than that of PU1000/PU2000 (50/50). So we measured the transmission loss (attenuation) of PU layer and copolymer having composition of PU1000/PU2000 (75/25) which shows a balance of damping efficiency and mechanical properties among the compositions of polyurethane investigated. In acoustic terms, absorption can be expressed as  $\alpha\lambda$  while in modulus terms,

absorption can be expressed as  $\tan\delta$ .  $\alpha$  and  $\lambda$  represent the attenuation coefficient and wavelength, respectively. So the acoustic and modulus approach are thus alternate and equivalent ways of describing the same physical phenomenon. For small  $\tan\delta$ , Ferry[2] pointed out that  $\alpha\lambda = 8.686 \tan\delta$  in unit of dB.

Figure 5 shows the transmission loss of PU copolymer having PU1000/PU2000 (75/25) composition as a function of frequency for extensional and constrained layer configurations. The transmission loss of steel plate indicates the measured value without the damping layer (polyurethane), and successive data show the value taken out the transmission loss of steel plate. It stands for pure transmission loss of PU layer and copolymer. As shown in Figure 5, the effect of constrained layer configuration is larger than that of extensional layer



**Figure 5.** Transmission loss of PU copolymer having the composition of PU1000/PU2000 (75/25) with frequency for extensional and constrained layer configurations.



**Figure 6.** Transmission loss of PU layer, PU copolymer and PU1000 with frequency for constrained layer configuration.

configuration in the experimental frequency range. Oberst[13] studied the extensional type and constrained layer damping, and reported that the latter yields better damping than the former. The higher modulus constrained layer (upper steel) like steel (see Figure 2) will increase the shear motion of the damping layer and have a greater dissipation, and thus greater damping is produced.

Figure 6 shows the transmission loss of PU layer, PU copolymer and PU1000 for constrained layer configuration. The transmission loss of PU layer and copolymer was more effective than that of PU1000 in low frequency range. We measured the transmission loss at  $-10^{\circ}\text{C}$  and damping at 1 Hz for samples. The height of damping peak of PU layer and copolymer shown in Figure 3(b) at  $-10^{\circ}\text{C}$  and 1 Hz were higher than that of PU1000. Since a decade of frequency increase is equivalent to an increase in temperature of approximately  $6\text{--}7^{\circ}\text{C}$ , the experimental frequency range of transmission loss corresponds up to about  $10^{\circ}\text{C}$  of damping peak. In this temperature range, the damping peak of PU layer and copolymer are always higher than that of PU1000. On comparing PU layer and copolymer, the transmission loss of PU copolymer is more effective than that of PU layer in this experimental frequency range. This result is well seen in Figure 3(b), in which the damping peak of PU copolymer is higher than that of PU layer in this temperature range.

### Conclusions

Polyurethanes are particularly attractive for a study of damping since it is possible to change their glass transition over a wide range of temperature through the changes in its structure. In this work, we measured the damping, mechanical properties, and transmission loss of polyurethane layer and copolymer. Since there is a trade-off between the damping efficiency and the mechanical properties, polyurethane layer and copolymer having the compositions of PU1000/PU2000 (75/25), which shows a balance of damping efficiency and mechanical properties, was studied. Their transmission loss was measured for application in noise reduction. Polyurethane copolymer was more effective than polyurethane layer and PU1000 in terms of damping and transmission loss in

temperature and frequency range employed in this study. As expected, the transmission loss of PU1000 was improved in low temperature range (low frequency range) by using PU copolymer and layer.

### Acknowledgements

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### References

1. L. H. Sperling, "Introduction to Physical Polymer Science", 2nd ed., pp.303-381, Wiley-Interscience, New York, 1986.
2. J. D. Ferry in "Viscoelastic Properties of Polymers", 3rd ed., pp.33-46, John Wiley & Sons, New York, 1980.
3. B. Hartman in "Encyclopedia of Polymer Science and Engineering", 2nd ed., Vol. 1, pp.131-160, Wiley-Interscience, New York, 1984.
4. Y. Imai and T. Asano, *J. Appl. Polym. Sci.*, **27**, 183 (1982).
5. H. Kothandaraman, K. Venkatarao, and B. C. Thanoo, *Polymer J.*, **21**, 829 (1989).
6. P. K. Saxena, S. R. Srinivasan, J. Hrouz, and M. Ilavsky, *J. Appl. Polym. Sci.*, **44**, 1343 (1992).
7. H. Weibo and Z. Fengchang, *J. Appl. Polym. Sci.*, **50**, 277 (1993).
8. G. Spathis, M. Niaounakis, E. Konton, C. Apekis, P. Pissis, and C. Christodoulides, *J. Appl. Polym. Sci.*, **54**, 831 (1994).
9. Y. C. Chern, S. M. Tseng, and K. H. Hsieh, *J. Appl. Polym. Sci.*, **74**, 328 (1999).
10. D. J. Hourston and F. U. Schafer, *Polymers for Advanced Technologies*, **7**, 273 (1995).
11. K. H. Yoon, S. T. Yoon, and O. O. Park, *J. Appl. Polym. Sci.*, **75**, 604 (2000).
12. Z. S. Petrovic, M. Ilavsky, K. Dusek, M. Vidakovic, I. Javni, and B. Benjamin, *J. Appl. Polym. Sci.*, **42**, 391 (1991).
13. H. Oberst, *Acustica, Akust. Beih.*, **2**, 181 (1952).