Reports Res. Lab. Asahi Glass Co., Ltd., **53** (2003)

UDC：629.3.023：678.664

11. Novel Polyether Polyol Designed for High Performance Automotive Seating Foams

Takayuki Sasaki*, Hiroshi Wada*, Akio Horie*, Hisakazu Harada*
Yoshiyuki Murata and Daisuke Takagi****

Various studies have been conducted to improve the properties of a flexible polyurethane foam for automotive seating applications. For example, in order to improve comfort of a seat cushion to sit on, improvements of impact resilience, vibrating property and durability have been tried. Furthermore, in recent years, along with changes of customers' Preference of comfort to sit on, a flexible polyurethane foam having a low impact resilience coefficient has been desired. Asahi Glass Urethane Co., Ltd. (manufacturer of polyether polyol, and last year its R&D Div. was transferred from Aasahi Glass Co., Ltd.,) has developed a high performance novel polyester polyol: PREMINOL-S (PML-S) having a higher molecular weight and a lower degree of mono-ol in comparison with conventional PREMINOL to respond to the requirements of customers. Actually, in order to respond to customer requirements, evaluations of automotive seating cushions or human comfort using PML-S series polyols were carried out in cooperation with Araco Corporation. As a result, we have been succeeded in achieving high vibrational absorption and high durability for an automotive seating cushions.

1. Intoroduction

In recent years, it has been demanded to improve the fuel consumption efficiency for environmental reasons, the riding comfort for customers and the width of the cabin space. Since the seat cushions have a large volume in automotive cabin space, it is desired to reduce their weight and thickness. And also, it is of the most important factors to improve the riding comfort. Usually, an automotive seat consists of seat pads, springs and steel frames. Previously, in Japanese automotive industry, the polyurethane foams for seat cushions had been made with hot molding processes. In the last ten years, the full foam cushions (so-called high resilience type), which function as both seat pads and springs, have been widely used to reduce the weight of automotive seats.

Concerning to the direct influence of automotive body vibration to a human body, the importance of keeping low vibration transmissibility in frequency range has been considered but not clarified. (for example the range from 2 to 8 Hz or 10 to 20 Hz).

However, in recent studies, it has been found that high resilience type seat pads have higher transmissibility at a resonance frequency but it have not been enough to support the crew's body and depress the vertical vibration. Namely, some researchers showed the way to solve above issues by depressing the resilience and high transmissibility [(1),(2)].

Previously, we have reported the improvement of the vibration characteristics by using PREMINOL (PML) series polyether polyols, they have lower unsaturation values (USV) than conventional types[(3)~(5)]. We successfully developed the PREMINOL-S (PML-S) whose USV is lower than previous PML series.

* Asahi Glass Urethane Co. Ltd., Japan **Araco Corporation, Japan

By using PML-S type polyol, the vibration transmissibility of the foam can be controllable the special cell structure in the foam. We developed a seat pad made from PML-S and evaluated the physical properties compared with two conventional foams. Further, it was found that PML-S could reduce the thickness of the seat cushions without deteriorating vibration characteristics and durability.

On the other hand, the problem of organic volatility from polyurethane foam has been reported in recent years[6]. A reactive amine catalyst having a mono-ol is usually used to dissolve the problem. In general, mono-ol worsens the physical properties, especially vibration characteristics and durability. However, in case of the hyper low USV polyol, the reactive amine catalyst having a mono-ol is useful for the problem with keeping the physical properties. And we also showed vibration characteristics and durability of the foam by using PML-S and a reactive amine catalyst.

2. EVAluation and Experimental

1) Polyether polyols

Total unsaturation value of PML-S 7980 is 0.015 meq/g, Mw is 7000 and functional number is 3. PML-S 7980 is a main grade of PML-S series.

2) Formulation

A formulation is shown for seat cushions and molded samples in **Table 1.**

Table 1 Evaluated Formulation. (ppw)

Polyether Polyol／Polymer Polyol	100
Cross Linker	1.5〜3.5
Amine Catalysts	0.5〜0.6
Silicone Surfactant	1.0〜1.5
Water	2.5〜2.8
Isocyanate(NCO=44.8%)* Index	Variable

*C-1021: Produced by Nippon Polyurethane Industry Co., Ltd

3) Preparation of foam samples

Molded foams and seat cushion samples were made using high-pressure machine (Henneche MEG-HK-430, MQ-25).

In order to investigate the seating performance for automobiles, we selected the driver's seat of Japanese Multipurpose Passenger Vehicle (MPV). The high performance riding properties on various road surface and speed was demanded for the driver's seat of MPV. Other process conditions of machine blowing are summarized in **Table 2.**

Table 2 Process Condition at High Pressure Machine Foaming.

High Pressure Machine			HenneheMEG-HK-430 (MQ-25)
Shot Rate		(g/s)	400
Shot Pressure	Polyol	(M Pa)	14
	Isocyanate	(M Pa)	14
Stream Temperature	Polyol	(˚C)	25
	Isocyanate	(˚C)	25
Test mold size		(mm)	400×400×100, 400×400×70
Demold Time		(min)	6
Mold release agent			Chukyo yushi kougyo B-760

4) Manufacture of seat cushions

Two Polyurethane seating cushions (sample A and B), which had different visco-elastic characteristics, were made as reference samples. One (sample A) has high resilience properties and another (sample B) has low resilience properties. In order to exclude the influence of seat shapes, both samples made from conventional polyether polyol and polymer-dispersed polyol, were foamed in same mold. After adjusting the hardness of the seat cushions, according to JIS K6400, impact resilience (method A), hysteresis loss, airflow values, stress relaxation, and so on, were measured.

5) Vibration test of seat cushions and molded foams

Vertical vibration tests of molded samples and seat cushions were carried out in accordance with JASO B407-87. In order to compare the polyurethane vibration characteristics, seat cushions were fixed on a seat flame without fabric. The vertical vibration machine was electromagnetic controlled G24-230 type, Shinken-sha, and measurement conditions are shown as below;

・Vibration plate: TEKKEN type, load 490N measurement
・Frequency band : 1〜12Hz

6) Vibration test of seat cushions (Six Axes Shaker)

In order to clarify the influence of actual vibrations from a road surface, after collecting the random output from actual driving information for MPV, the simulation of the vibration wave shape was carried out with a six axes shaker manufactured by MTS Systems corporation, then vibrational characteristics for the human body sitting on the automotive seating cushion were measured. Driving courses (test courses) were selected from road surface conditions based on distinctive vibrations, (1): rough road and low speed, (2): normal road and high speed, (3): concrete road and high speed. Panelists sat on the assembled seat cushions equipped with accelerometers under the hips on the six axes shaker.

7) Sensory inspection by panelists

Four Japanese male skilled panelists, who have over ten years of carrier, evaluated sensory inspection and vibration test using six axes shaker.

3. Result and Discussion

3.1 Vibration test for automobile seat cushions

The influence on the human body at each frequency is shown as below, [7]

- 2-4Hz: " Hyoko Hyoko " by a driver's up-and-down motion
- 4-8Hz: Pressure to the abdominal region
- 8-Hz: " Gotu Gotu ", " Buru Buru ", " Biri Biri " for the femur

In case of driving on a actual road, it is important to keep the transmissibility low for the improvement of comfort in all frequency range. Conventional seat cushion A and B are different in visco-elasticity and their vibration results are shown in **Fig. 1.**

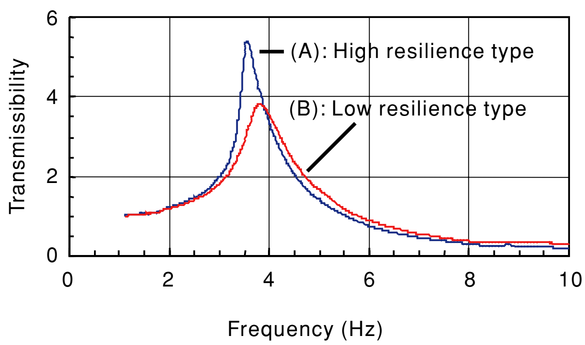

Fig. 1 Behavior of vibration characteristic.

When the vibrating characteristic of the seat cushions A and B is compared, seat cushion A is more excellent in the vibrating absorption capability in a high frequency zone. On the other hand, seat cushion B is excellent in the vibrating absorption capability in a low frequency (resonance frequency) zone. That is, with the conventional seat cushion, vibrating absorption performance is not satisfactory in all frequency range at same time, and a seat cushion must be chosen in accordance with the vibrating characteristic of vehicles.

3.2 Development of a new high performance polyurethane foam

It is known that the usage of a high activity silicone surfactant is an effective technique for the reduction of transmissibility at a resonance frequency. However, if this technique is applied, the rib frames around the cell in a polyurethane foam become thin, and this causes undesirable results such as deterioration of durability, shrinkage by closed cells etc.

In order to manufacture the polyurethane cushions having low vibration transmissibility and high durability, we developed a new high active polyether polyol: PML-S type.

When this polyether polyol is used, an early resin reaction is fast and the rib around a cell is formed thickly. In connection with this, the skin on a cell is also formed thickly.

This situation of the rib and cell after foaming and crushing is illustrated in **Fig. 2**. In the case of conventional high resilience foam, the skin is thinly formed on a cell after foaming (1), and the skin is removed completely by the crushing process (2). In the case of PML-S, a thick skin is formed after foaming (1) and some part of the skin remains after crushing (2). Then, by choosing crushing condition, we can adjust breathability (air flow) by controlling

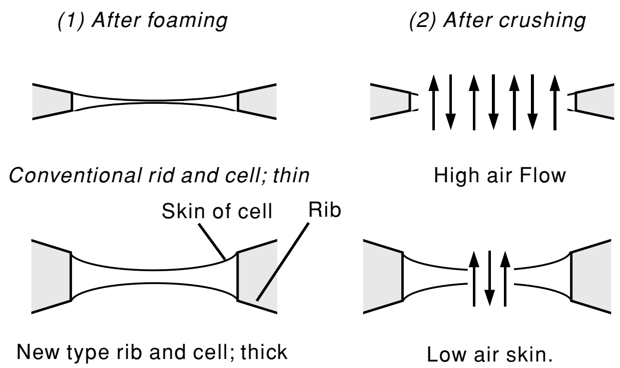

Fig. 2 Structure of rib and cell with skin.

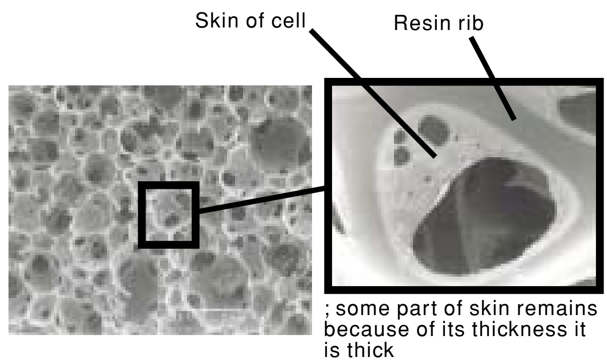

Fig. 3 SEM images of cell structures.

the amount of remaining skin. The images of the cell (after crushing) are shown for PML-S type in **Fig. 3**. Moreover, the thick rib structure secures the durability.

3.3 Evaluation of developed high performance seat cushion.

At this time, we have developed a novel performance seat cushion made from PML-S series polyol. **Table 3** shows the visco-elastic characteristics (static properties) of developed seat cushions. Sample A and B were formed using the same shape mold described before. Developed seat cushion shows almost the same hysteresis loss with lower resilience than sample A. It is presumed that the unique feature of developed foam, made from PML-S, is originated by unique cell structure. In other words, it is not the differences in resin characteristics but the differences in the polyol viscosities that affect the cell structure and control the airflow.

Table 4 and **Fig. 4** shows results of vibration tests. Developed seat cushions shows the lowest vibration transmissibility at resonance frequency in three cushions and resonance frequency was lower than that of seat cushion B (low resilience type).

Table 3 Visco-elastic Characteristic of Seat PAD.

Index		Sample (A)	Sample (B)	Developed
Core - density	g/cm^3	0.052	0.057	0.057
25%ILD (Identity Load Deflection)	$N/314cm^2$	250	257	254
Amount of strain (at load of 196N)	mm	10.5	10.5	10.9
Static spring constant (at load of 196N)	N/mm	6.1	8.9	7.5
Ball rebound (core)	%	70	58	63
Hysteresis loss	%	21.7	27.1	21.3
Stress relaxation rate	%	11.7	14.2	11.8
Air flow	L/min	82.1	34	21.5

Table 4 Vibration Characteristic of Seat PAD.

	(A)	(B)	High Performance Seat Cushion PAD
Resonance frequency (Hz)	3.5	3.78	3.62
Transmissibility At Resonance frequency	5.57	3.84	2.99
Transmissibility at 10Hz	0.21	0.32	0.23

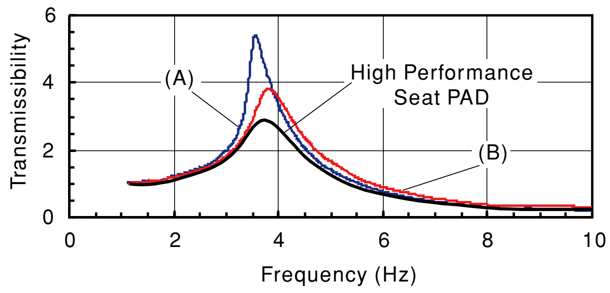

Fig. 4 Behavior of vibration characteristics.

Furthermore, transmissibility data at 10Hz of developed seat cushion are the same as those of high resilience type A. These results indicate that it is possible to lower the transmissibility by air damping in the cells, with keeping high resilience properties. Then we have developed the superior seat cushion with an ability of high vibrational absorption for all frequency zones. Consequently, it is expected to improve riding comfort on driving.

3.4 Evaluation of seat cushions by 6 axes shaker

After evaluation of vertical vibration, these cushions were assembled into the same fabrics. Firstly, the vibration wave shape was collected from each road surface and was put into the 6 axes shaker. The frequency analysis is shown on **Fig. 5**,**6** and **7. Fig. 5** is the result of rough road with high speed. With respect to the range of 1-5Hz (the most characteristic feature of slow driving on a rough road), the seat composed of the developed cushion shows the most excellent vibrational damping. **Fig. 6** shows the results of normal road surface with high speed, that indicates the seat composed of the developed cushion has the best vibration damping at the range of 10-15Hz. And also **Fig. 7** shows the excellent damping effect to vibration at the range of upper 20Hz on a concrete road surface with high

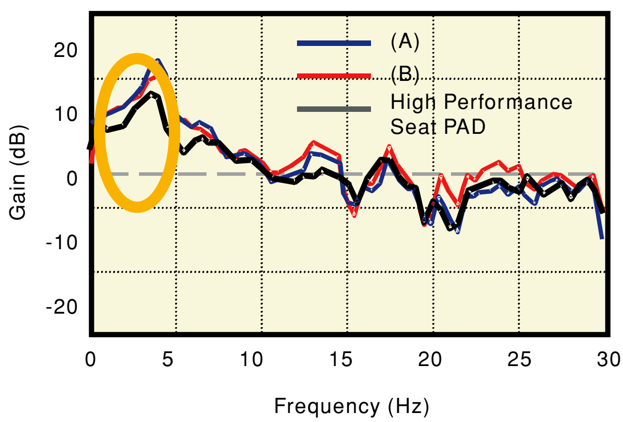

Fig. 5 Results of frequency analysis on the rough road surface (low speed).

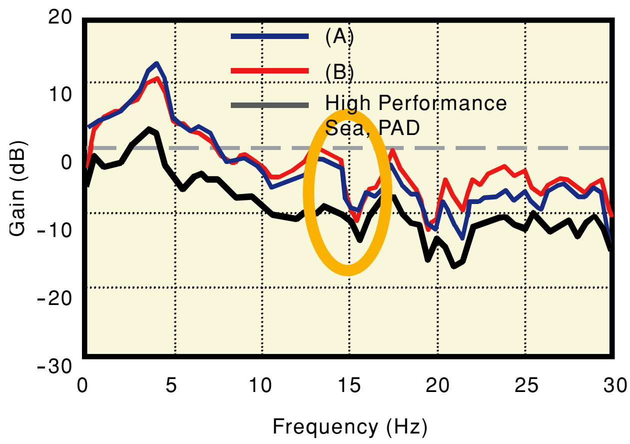

Fig. 6 Results of frequency analysis on the normal road surface (high speed).

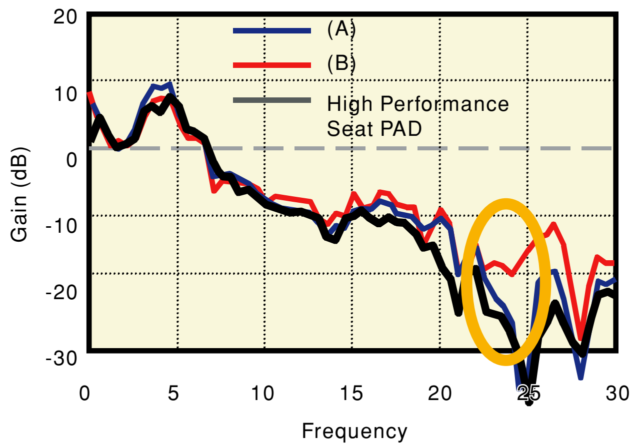

Fig. 7 Results of frequency analysis on the concrete road surface (high speed).

speed. According to the results above mentioned, it's realized that the seat composed of the developed cushion performs the excellent ability of vibrational damping for all frequency zone.

On the other hand, **Table 5** shows the results of sensory evaluation by the panelists. From the results, it is estimated that the developed seat cushion could improve the riding comfort and total performance of automobile seat.

Table 5 Results of the Sensory Evaluation.

Samples	Value	Notices
High Performance Seat PAD	3.5	; Vibrations were mild at wide range
(A)	3.0-	; FUWA FUWA was high
(B)	3.0+	; BURU BURU was high

3.5 Relationship between vibrational characteristics and thickness of foams

Recently, expansion of cabin space and improvement of riding comfort is desired according to the increased demand of the compact class vehicles. If the seat cushion could reduce its thickness, it is possible to widen a permissible range of the body design. In this point, we have investigated the developed foam properties (vibration characteristics and durability) in relation to thickness. The vibration characteristics test results of the foam samples are shown in **Fig. 8** and **Fig. 9**. And the results of durability test are shown in **Fig. 10** and **Fig. 11**. In vibration characteristics, both developed foam using PML-S and high resilience type foam indicates higher resonance frequency at 70 mm thickness compared with 100mm thickness (**Fig. 8**). And also, vibration transmissibility at resonance frequency of 70mm foams is lower than that of 100mm foam (**Fig. 9**). On

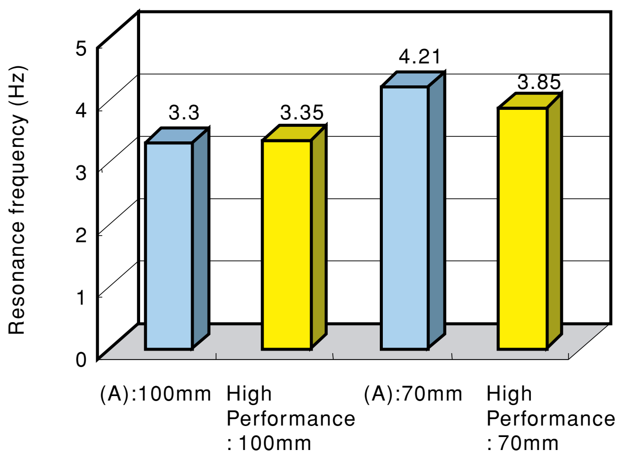

Fig. 8 Resonance frequency at 70mm and 100mm foam thickness.

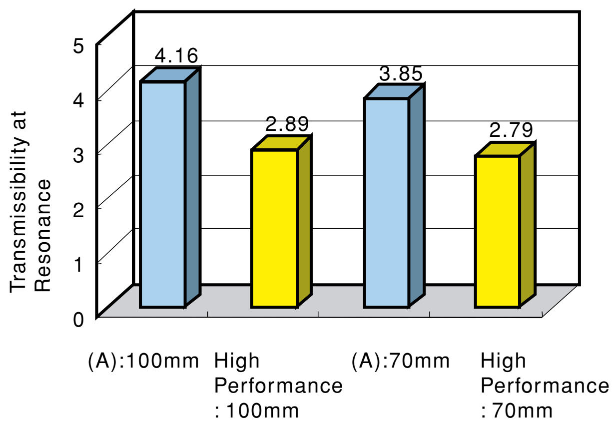

Fig. 9 Vibration transmissibility at resonance frequency for 70mm and 100mm foam thickness.

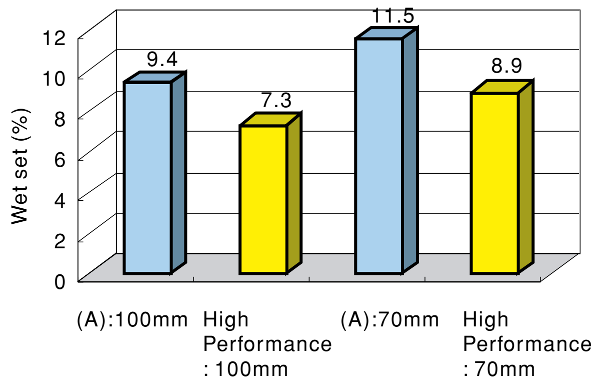

Fig. 10 **Wet Set at 70mm and 100mm foam thickness.**

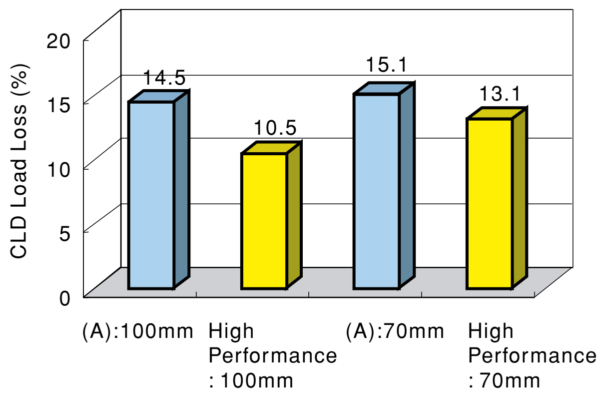

Fig. 11 **CLD Load Loss at 70mm and 100mm foam thickness.**

the other hand, the developed foam has superior durability to high resilience foam. (durability test; **Fig. 10**: wet compression set; aging condition 50°C, 95% RH, for 22 hours, **Fig. 11**: fatigue by constant-load pounding test) Therefore, the developed foam using PML-S has excellent vibration characteristics and durability at 70 mm thickness compared with high resilience foam.

3.6 Amine emission free Foam

Recently, the issue of organic volatility from polyurethane foams in an automobile is growing. In order to solve the issue, usage of the reactive amine catalyst having reactive function in its molecule is proposed. Because of the increase in the mono-ol content, it is not favorable to use the reactive amine catalyst with conventional polyols. **Table 6** shows the ratio of mono-ol in polyether polyol and the mixture of polyether polyol and reactive amine which containes hydroxyl group. Amine catalysts used in this test are following.

Triethylenediamine: non-reactive amine catalyst (conventional)

Bis (2-dimethylaminoethyl) ether: conventional type：non-reactive amine catalyst(conventional)

Table 6 **Influence of the Reactive Amine Catalyst in PPG System to Seating Foam Properties.**

	Ratio of OH-Group in PPG system (%)			
	PPG	Monol		
	Actual PPG	Derived from PPG	Reactive Amine Cat.	total
Conventional PPG	80	20	—	20
Conventional PPG+Reactive Amine Cat.	68.9	17.3	13.8	31.1
PREMINOL-S	96.8	3.2	—	3.2
PREMINOL-S+Reactive Amine Cat	83.4	2.8	13.8	16.6

Reactive Amine-Cat : (CH3)2N(CH2)6-OH

Table 7 **Evaluating Results of PML-S Systems with Reactive Amine Catalyst.**

Examination Item		Typical Formulation	Trial-1	Trial-2
PML-S		60	60	55
Polymer Polyol		40	40	45
Cross Linker		1.0	1.0	1
Amine Catalysts	None-Reactive	0.52	—	—
	Reactive	—	1.0	1
Silicone Surfactant		1.2	1.2	1.2
Water		2.5	2.5	2.5
Isocyanate	Index	100	100	105
Core - density	g/cm³	0.056	0.1	0.056
25%ILD	N/314cm²	230	198	220
Hysteresis loss	%	16.6	17.1	16.9
Resonance frequency	Hz	3.4	3.6	3.5
Transmissibility at Resonance fequency	—	2.9	2.5	2.6
Transmissibility at 10Hz	—	0.20	0.26	0.24
Fogging Value (Mass metod)		0.30	0.13	0.10

※ Mold: 400×400×100mm

N,N-dimethylaminohexanol (Kaolyzer No.25 made by KAO Corp.)： reactive amine catalyst

Table 7 shows a typical formulation of cold cure foams and several experimental data. Although the hardness of the foam using reactive catalyst tends to decrease slightly, it is effective to reduce the amine emission without deteriorating the physical properties by using the combination of PML-S and the reactive amine catalyst.

4. Conclusion

1. By using novel polyether polyol (PML-S series), it is possible to lower the vibration transmissibility of a foam without deteriorating the durability.
2. Actual seat cushions using PML-S has excellent vibrational absorption in wide frequency range.
3. It was clarified that there was a good relation between the data obtained from a visco-elastic characteristics by vertical vibration machine and a 6 axes shaker on actual driving data.
4. PML-S series can give a wide permissible range of the body design because they make it possible to reducing the foam thickness keeping the vibration properties and durability.
5. PML-S series has hyper low unsaturated value. It is possible to reduce the organic emissions from polyurethane foam using reactive amine catalysts without deterioration of physical properties, vibration properties and durability.

—Ackowledgements—

The authors would like to thank to Mr. Hatano, Mr.Kimura and Mr.Ito in the research and development center, Asahi Glass Urethane Co., Ltd., to support this work.

—References—

(1) M.Isobe, K.Usaka, H.Utsumi and K.Ohkubo, Proceeding of the Polyurethanes EXPO'2001, 267 (2001).
(2) K.Saiki, S.Murakami, M.Hayashi and T.Fukami, Proceeding of the Polyurethanes EXPO'2001, 255 (2001).
(3) S.Hatano, N.Yasuda, S.Hayashida, N.Kunii, H.Takeyasu and S.Kozawa, Polyurethanes World Congress 1991, 112 (1991).
(4) Y.Toyota, N.Hasegawa, H.Wada, A.Horie, S.Hatano, T.Sasaki and S.Oki, Proceeding of the Polyurethanes World Congress 1997, 421 (1997).
(5) Y.Toyota, H.Wada, A.Horie, T.Sasaki, K.Takahashi and H.Takeyasu, Proceeding of the Polyurethanes EXPO' 99, 389 (1999).
(6) Sakai, A.Ishikawa, M.Mori and K.Kikuchi, Proceeding of the Polyurethanes EXPO '2001, 33 (2001).
(7) Published Society of Automotive Engineers of Japan, Inc. Shinhen Zidousya kougaku binran, Second revised edition.