Asian Journal of Chemistry; Vol. 25, No. 9 (2013), 5215-5220

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2013.F20

Advancement of Noise, Vibration and Harshness (NVH) Performance of Vehicle Rubber Hoses†

H.S. JUNG[1], S.H. LEE[1], H.S. WOO[2], M.S. KIM[2], H.H. PARK[2] and B.K. MIN[1,*]

[1]Polymeric Materials Research Team, Hyundai Motor Company, Hwaseong 772-1, Republic of Korea
[2]Fluid Material Team, Hwaseung Material Co.Ltd., Yangsan 147-1, Republic of Korea

*Corresponding author: Fax: +82 31 3682739; Tel: +82 31 3687423; E-mail: spinwave@hyundai.com

AJC-13176

This study assessed an approach in terms of materials for improving the noise, vibration and harshness (NVH) performance of a rubber hose. Ethylene propylene rubber for the heater hoses in a cooling system and acrylic rubber (AR) for the intercooler hose in an air intake system were chosen for mixing to improve the vibration and noise performance. Both ethylene propylene rubber and acrylic rubber were modified by changing the compound of the base polymer, reinforcement filler and additives. Dynamic mechanical analysis was used to measure the viscoelastic properties, such as the storage modulus and loss factor (tan δ). A vehicle acceleration test was also conducted to observe the indoor changes in the NVH performance of rubber hoses.

Key Words: Heater/Intercooler hose, Noise, Vibration, Harshness, Ethylene propylene rubber, Acrylic rubber.

INTRODUCTION

Following the global trend of high performance and low fuel cost, modern automobiles are developing appreciably through downsizing and increasing the output of the power train. On the other hand, vibrations of vehicles has increased by more than 10 % of the past generation and the weight-lightened car structure is weaker at transmitting the vibration and noise.

The performances of vibration insulation on auto parts are very important factors when developing vehicles. The course of the inflow of vibration and noise can be classified into two areas *viz.*, the engine room or road vibration goes through the medium of a solid object and the driving noise or combustion noise penetrates indoors by transmission through air.

The ways to insulate sound *via* a solid are to increase the hardness, install a damper and substitute electronic components. On the other hand, this is difficult to apply because of the reduced fuel efficiency according to the car's weight. The way to insulate sound effectively by a solid is to use anti-vibration rubber. Relatively silent vehicles can be obtained by increasing the dynamic characteristics and damping performance of anti-vibration rubber. Studies of anti-vibration rubbers have been pushed forward vigorously. The aim is to develop an engine mount with a low hardening factor, high damping hydro bush *etc*. In addition, improving the insulation of a rubber hose is one way of blocking the inflow sound *via* a solid. The hose is basically the path for an inner fluid between the parts. The hose needs to maintain its function under the worst environmental conditions and supply fuel, cooling water and lubricant. On the other hand, vibration and noise can be transferred to the opposite parts. Normally, rubber has considerable flexibility compared to iron. Although a metallic and plastic pipe has excellent durability, the hose cannot be replaced completely because of the insulation problems of vibration and noise[1,2].

One way to close off air borne sound effectively is to use a material strengthened on sound insulation and sound absorption and to eliminate the sympathetic sound of the tyres. This can reduce noise from the engine and road. Studies on shutting off air borne sound are being promoted. For example, the development of complex sound-absorbing materials made from a porous film, the development of a wheel that can absorb the tyre resonance sound and the development of glass with improved high frequency sound insulation.

Dynamic property of rubber: Rubber is used because it can undergo repetitive deformation quickly by regular frequencies within a regular range. For example, the side and floor of the rotating tyre and the engine mount to shut off vibration from the engine to the car body. The dynamic property is affected by a change in temperature, frequency

†Presented to the International Rubber Conference (IRC-2012), May 21-24, 2012, Jeju, Republic of Korea

and filler in large deformation. The dynamic property is irrelevant to a change in tiny deformation (linear viscoelastic) and the temperature-frequency can be overlapped in case of significant deformation. These characteristics can be used to predict the dynamic properties from the extensive range of frequencies. Dynamic properties of different amorphous rubbers, which is similar to a filler that is not added in the same condition[3,4].

The glass transition temperature is a commonly standard. On the other hand, the mechanical properties of rubber are not elastic at the glass transition temperature. The frequency from the glass to rubber state can be a proper standard in rubber. The frequency that shows a transition from a rubber state to a glass state at a given temperature can be adopted. The dynamic behaviour is changed by the chemical structure of rubber according to the frequency. The dependence on the molecular weight, molecular distribution and curing density are similar in each rubber.

Generally, the dynamic property of rubber is sensitive to deformation and stress changing periodically, which can be shown with a phase difference at the same frequency. Y is the strain of specimen, which is comprised of two parallel boards similar to that shown in Fig. 1. The strain is defined as the tangent of a hexahedron or the length divided by the height when the upper board is moved against a fixed lower board. The stress (σ) is the shear force per unit area causing deformation. The strain changes according to eqn. 1 when the specimen undergoes shear deformation periodically.

$$Y(t) = Y_0 \sin \omega t \quad (1)$$

where Y_0 is the amplitude on deformation, ω is the angular frequency (the value is multiplied by the frequency, in which the unit is Hz by 2π) and t is time. The stress (σ) is changed periodically by the angular frequency (ω), as shown in Fig. 1. The phase difference is eqn. 2 due to moving ahead in time.

$$\sigma(t) = \sigma_0 \sin(\omega t + \delta) \quad (2)$$

The stress can be separated into two components, the same strain on phase and a 90º offset on the phase difference. The total stress is expressed in eqn. 3.

$$\sigma(t) = Y(t)\,[G'(\omega)\sin \omega t + G''(\omega)\cos \omega t] \quad (3)$$

where the definition of the shear modulus is G'(ω) and G''(ω). The storage modulus (G') is a criterion of the storage energy, it is restored for periodic deformation. The loss modulus (G'') is a criterion of the energy consumed by heat, the G''/G' ratio is tan δ or the loss factor.

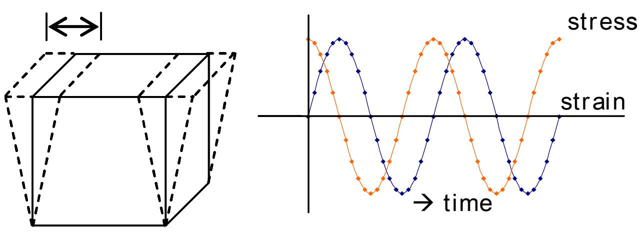


Fig. 1. Shear deformation changing periodically

Both the modulus values are a function of the frequency. The value of G' at low frequencies approaches the equilibrium modulus and the value of G'' becomes smaller. This shows that rubber has total elasticity at deformation in low frequencies. The values of G' and G'' increase with increasing frequency and become equal. The frequency represented phenomenon is determined by partial movement of chain molecules in rubber. If G' is increased, the value approaches the glassy state from the rubbery state and requires a high frequency at room temperature. Energy loss (tan δ) represents the maximum value on energy storage. This is closely related to the vibration insulation property and the control of wave propagation.

Young's modulus E' and E'' are used for simple tensile or compression deformation. These represent the modulus of the same phase and a 90º phase difference on the changing amounts of tensile deformation[5,6].

EXPERIMENTAL

Table-1 lists the materials used. The raw material for the heater hose was ethylene-propylene rubber (EPDM) and ethylene-polyacrylate rubber (AEM) and polyacrylate rubber (ACM) were used for the intercooler hose in intake system. The mixer used a Banbury (Mitsubishi/5 L) and Roll mixer (Korea Mtec / 8' × 20').

Analysis equipments: Dynamic mechanical analysis (DMA; GABO/EPLEXOR 150N) was used to measure the viscoelastic modulus of rubber. Dynamic mechanical analysis is used to measure the mechanical dynamic heat characteristics by changing the external force periodically on a specimen. The mechanical modulus of a material was measured as a function of temperature, frequency and vibration. The specimen makes the deformation by the periodical stress. The specimen is modified as it responds to stress. The mechanical modulus is determined from stress-deformation. The shear modulus G (shear stress) and Young's modulus E (stretching or bending) were measured according to the form of applied stress. The modulus and loss factor (tan δ) are dependent on the temperature and frequency. The storage modulus of a rubber substance ranged from 0.1 MPa to 10 MPa at room temperature.

Dynamic mechanical analysis provides information on the storage modulus and loss factor (tan δ) and is used to measure the extensive physical properties of a substance. In addition, the Shore A for measuring the hardness of rubber (Teclock /GS-709) and a micro durometer (Instron) were used and a universal testing machine was used to measure the elongation and tensile strength of rubber (Zwick-Roell/Z010)[7].

RESULTS AND DISCUSSION

Noise, vibration and harshness (NVH) performance of heater hose on vehicle heating system: Fig. 2 shows the driving noise of a Hyundai Motor Company (HMC) test car (diesel engine). The influence of the heater hose is the highest. The noise decreased at 100 to 500 Hz when the transmission mount shape was changed and at 100 to 700 Hz when the weight of engine support bracket was increased. The range of decreasing noise was the largest at 500 to 2,000 Hz after eliminating the heater hose at the dashboard side. The level of noise was quite high, even though the diameter or length of the heater hose was increased.

TABLE-1
LIST OF THE COMPOUNDING MATERIALS

	Material	Makers
Polymer	EPDM (Heater Hose)	KUMHO Polychem (Local)
C/Black	Carbon black	EVONIK
Filler	$CaCO_3$	EUJIN (Local)
Activator	Zinc oxide	HANIL CHEM (Local)
	Polyethylene Glycol	AKZO NOBEL
	$C_{18}H_{36}O_2$	LG HEALTH CARE (Local)
Vulcanizing agent	SULFUR	MIWON (Local)
Plasticizer	Paraffin oil	MIWON (Local)
Processing aid	Ester of saturated fatty acids	STRUKTOL
Accelerator	Morpholine disulfide	FLEXSYS
	Zinc di-*n*-butyl-dithiocarbamate	LANXESS
	Dipentamethylene thiuram tetra sulfide	LANXESS
	Tellurium diethyldithiocarbamate	AKROCHEM
	2-Mercaptobenzothiazole	LAXESS
	Tetramethylthiuram disulfide	FLEXSYS
Polymer	AEM (Intercooler Hose)	DUPONT
C/Black	Carbon black	EVONIK
Accelerator	Diphenylguanidine	LANXESS
Activator	Stearic acid	LG HEALTH CARE (Local)
Vulcanizing Agent	Hexamethylenediamine carbamate	INTERBUSINESS
Antioxidant	α,α-Dimethylbenzyl)diphenylamine	UNIROYAL
Plasticizer	Polyether ester	ADEKA PALMAROLE
Processing aid	Polyoxyethylene octadecyl ether phosphate	R.T. VANDERBILT
	Octadecylamine	AKZO NOBEL
Galley polymer	GALLEY ACM (Intercooler Hose)	TOPHE
C/Black	Carbon black	EVONIK, KCB (Local)
Accelerator	ZDBC	OCI (Local)
Activator	Stearic acid	LG HEALTH CARE (Local)
Vulcanizing Agent	Trimercaptotriazins	TOPHE
Antioxidant	4.4-Bis(α,α-dimethylbenzyl)diphenylamine	UNIROYAL
Plasticizer	Adipic acid ester	ADEKA PALMAROLE
Processing aid	Microcrystalline Wax	NIPPON SEIRO, STRUKTOL
	Fatty acid esters	

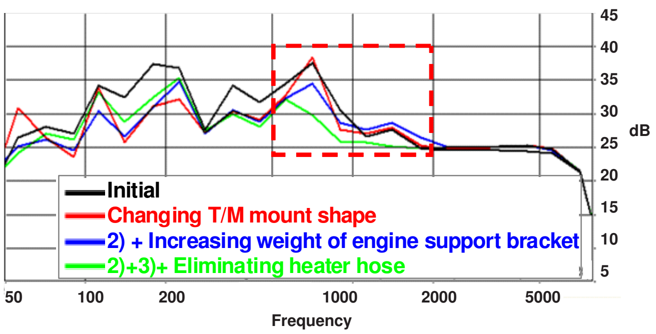


Fig. 2. Noise analysis of test vehicle

The insulation property was compared with that of a competitor's heater hose. The specimens were obtained from 8 companies (including Hyundai Motor Company) and there were 10 types of heater hoses. The storage modulus (0.1-100 Hz at 24 ºC) and hardness are represented by the changing frequency (Fig. 3). The storage modulus is the ratio of the deformation and storage stress (eqn. 4).

$$E' = \sigma'/\varepsilon = E^* \cos \delta \qquad (4)$$

where σ' is the storage stress, ε is the strain and E* is the complex modulus.

The hardness of A_1 and B_1 was 65 Hs, which was the lowest value, as shown in Fig. 3(a) and the hardness of Hyundai Motor Company and B_2 was 74 Hs, which was the highest value.

The storage modulus of A_1 and F was a minimum at 100 Hz (Fig.3 (b)). The storage modulus was A_1: 18.9 MPa, F: 22.0 MPa, HMC: 28.9. The Hyundai Motor Company product was fourth among the products from the 10 companies. As described in the introduction, the storage modulus is the criterion of the storage energy and the degree of restoration at periodical deformation. When the storage modulus is high, the external stress is proportional to deformation. The phase difference (δ) between stress and deformation was 0°. In other words, when the storage modulus is high, it will become close to an idle solid so it can respond to external stress immediately. On the other hand, as the storage modulus is low, a part of deformation is appeared behind the stress. The phase difference (δ) became close to the maximum of 90°. When the storage modulus is low, the insulation and damping performance of the parts can be increased. Therefore, the insulation performance of the A_1 and F heater hose was indentified indirectly by the above data compared to that of the other companies. The rubber compound was prepared to improve the insulation performance. The target was a storage modulus of 19.0 MPa of A_1.

The storage modulus was measured to compare the insulation performance of the Hyundai Motor Company conventional and A_1 products (Fig. 4). The frequency ranged from 0.1 to 100 Hz and the temperature was 24 ºC. The storage modulus of the developed compound was 16.3 MPa at 100 Hz, which is much better than the conventional product. In

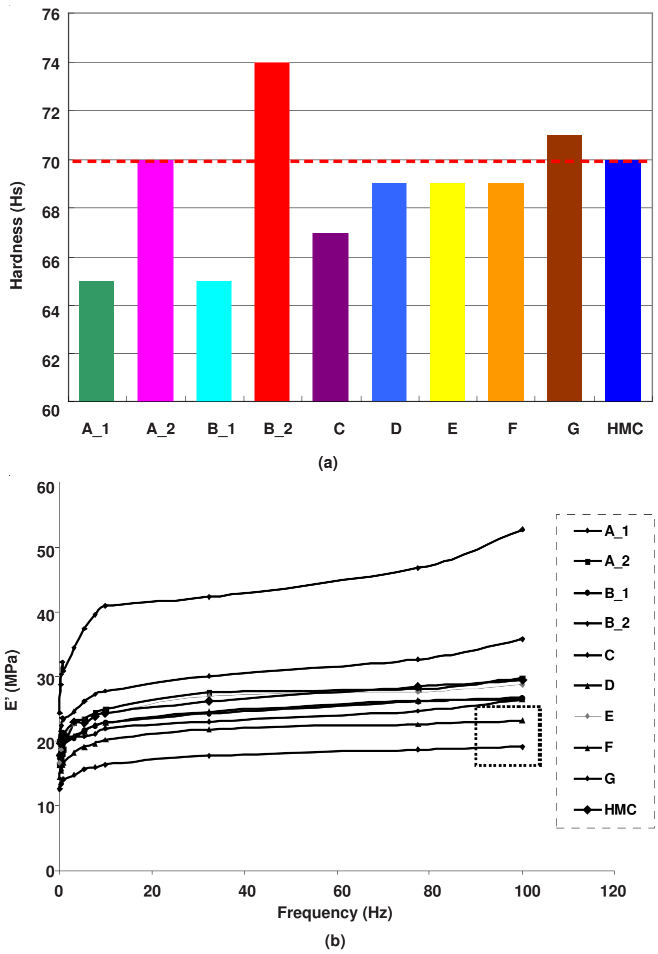
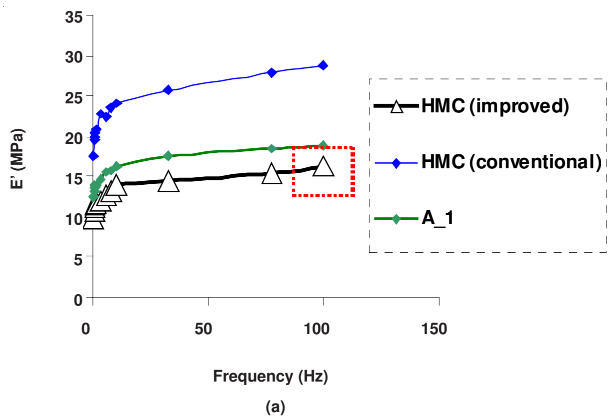


Fig. 3. The analysis results of competitor's heater hoses: (a) hardness test, (b) storage modulus (E′)

addition, it was better than A_1, which exhibited excellent NVH insulation performance.

The driving noise test showed that the level of new compound was lower than the conventional product [Fig. 4(b)]. When driving at 1,000 Hz and over in the cold circumstance test, the noise level decreased by 2 dB compared to the conventional product. A driver can notice a 2 dB reduction. The level was considered the same as that when installing a 1kg weight damper. Table-2 lists the physical properties of the heater hose material. The hardness decreased but the tensile strength and elongation was maintained. Table-3 lists the material for the heater hose. The raw material ratio, which is the



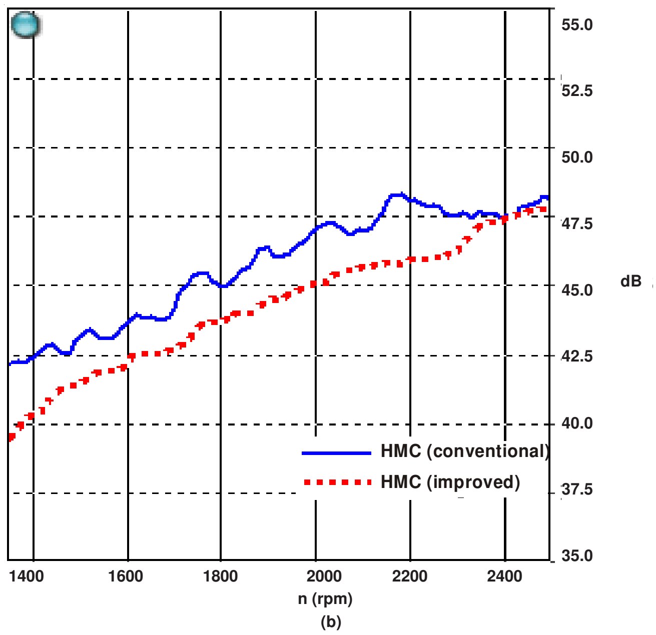


Fig. 4. The analysis results of improved heater hoses: (a) storage modulus (E′), (b) result of driving noise test

TABLE-2
MECHANICAL PROPERTIES OF THE HEATER HOSE

Properties	EPDM		
	HMC (conventional)	HMC (improved)	A_1
Hardness (Hs)	70	65	65
Tensile strength (MPa)	11.0	10.5	10.3
Elongation (%)	350	330	400

TABLE-3
CHANGED DETAILS OF THE COMPOUND (HEATER HOSE)

EPDM Compound (%)	HMC (conventional)	HMC (improved)
Polymer	25.50	29.50
C/Black	39.00	38.10
Filler	14.80	11.30
Activator	2.20	2.50
Sulfur	0.12	0.10
Accelerator	0.80	1.02
Plasticizer	17.10	16.90
Processing aid	0.50	0.60
Total	100	100

polymer, was increased by *ca.* 4 wt %. The Mooney viscosity decreased from 82 to 58 at ML1+8 (125 ºC). In addition, carbon black decreased *ca.* 1 wt % when mixed with FEF (size: 50 nm) and SRF (size : 70 nm) at a 1:1 ratio. The conventional compound used only FEF carbon black. The curing system was changed from semi-EV to EV (Effective vulcanization). The EV system has a higher ratio of vulcanization-accelerator and can avoid a decrease in heat resistance. The compression was set according to the increasing sulfur content.

NVH performance of intercooler hose on vehicle intake system: The vibrations of the vehicle floor is excessive because of the decreasing NVH performance of the intercooler hose, as shown in Fig. 5, at the idle state of the test vehicle (diesel engine). The change in the noise level was more than 4 dB in accordance with the changing outdoor temperature in the idle state. In addition, the insulation property, which is the other company's vehicle, was lower than Hyundai Motor Company at all temperature. The analysis was performed to compare with the insulation property of the intercooler hose, which is a competitor's vehicle. The specimens were obtained from a total of 4 companies and 6 types of intercooler hoses were used. Fig. 6 shows the loss factor value at 27.5 Hz in -50 ~100 ºC and the hardness value. The loss factor is the loss modulus per storage modulus, as expressed in eqn. 5.

$$\tan\delta \text{ (loss factor)} = E''/E' \quad (5)$$

where E'' is the loss modulus and E' is the storage modulus at eqn. 4.

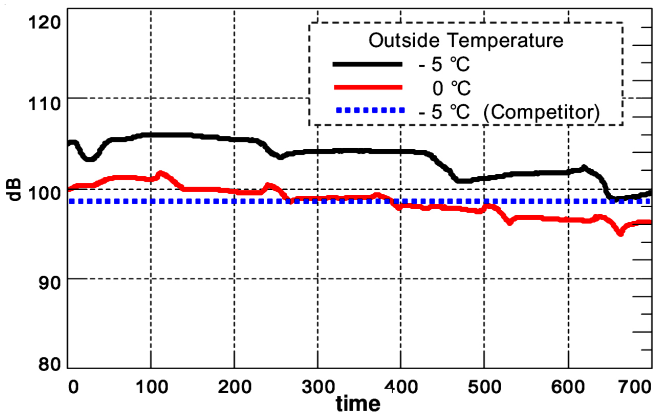
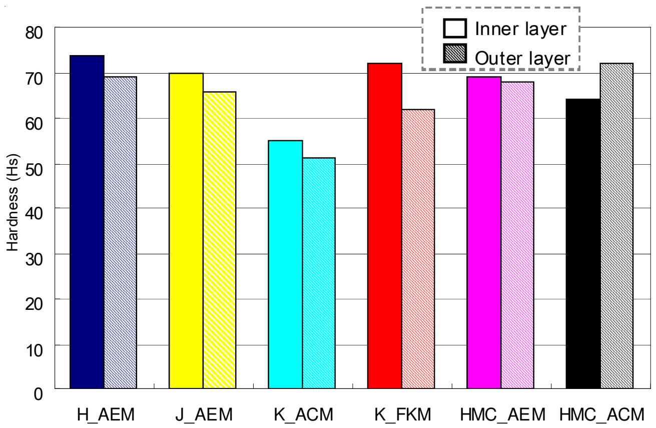


Fig. 5. The change of vehicle floor vibration at idle state



(a)

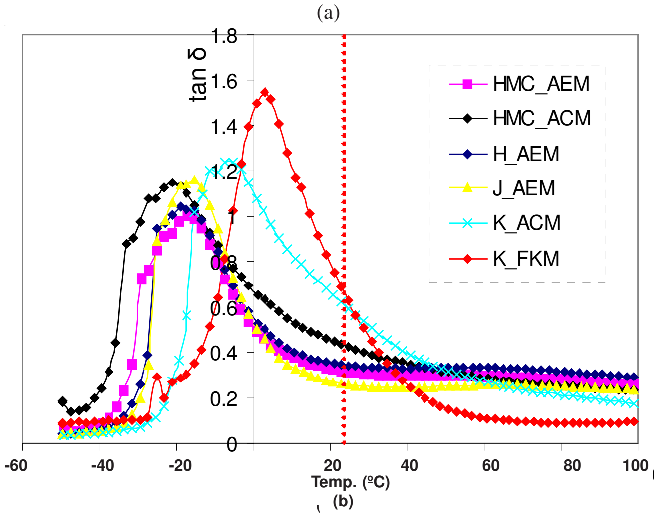
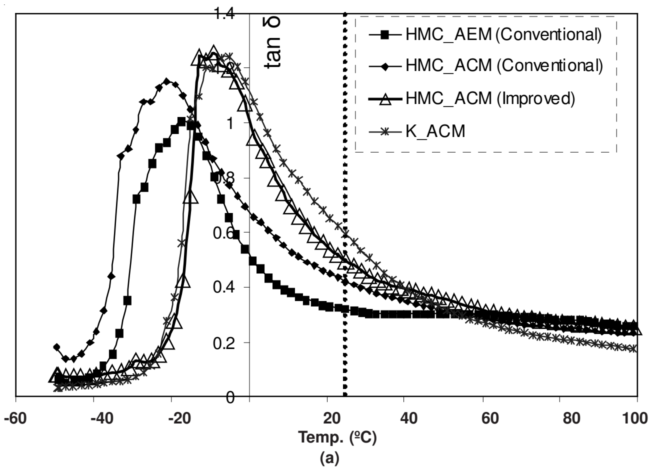
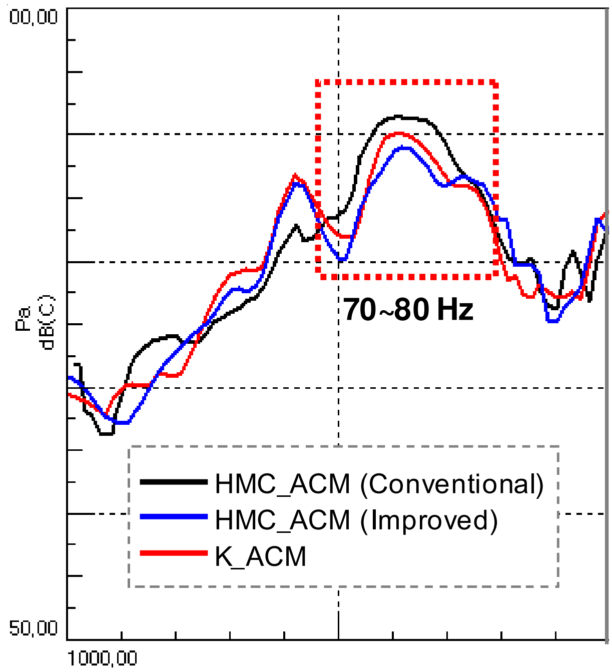


Fig. 6. The analysis results of competitor's intercooler hoses: (a) hardness test, (b) loss factor (tan δ)

The inner and outer hardness was 74/69 Hs in H_AEM, as shown in Fig. 6, which was the maximum value. 55/51 Hs for K_ACM was the minimum value. As shown in Fig. 6(b), the loss factor value was a maximum in K_ACM and K_FKM at 25 ºC. Loss factor values were K_ACM : 0.60, K_FKM : 0.63, HMC_ACM : 0.42, which is the middle level among the 6 companies. As described above, the loss factor is the loss modulus per storage modulus, which is proportional to the loss modulus and loss factor. As the loss modulus value was increased, deformation by time was generated according to the external force phase difference (δ) of stress and the deformation was a maximum of 90º. As the loss modulus is increased it will become close to that of an idle liquid. The stress is proportional to strain rate applied at an idle liquid. The phase difference between stress and strain was 0º when the loss modulus was low. The external stress responds immediately when the loss modulus is low. The damping performance of the parts will be increased with increasing loss factor and high loss modulus. Therefore, the intercooler hose is judged to be excellent compared to the other products, K_ACM and K_FKM. The compound of the intercooler hose was examined to improve the NVH insulation performance. The target of the loss factor of K_ACM was 0.6. FKM showed the highest loss factor but an additional test to compare with ACM rubber was not conducted. The loss factor of the new compound was compared with conventional products and K_ACM and showed an improvement in the new compound, as shown in Fig. 7(a). The temperature range was -50 ~ 100 ºC and the frequency was 27.5 Hz. The loss factor of the developed compound was 0.50 compared to the Hyundai Motor Company conventional products which value is 0.42 at 25 °C. This shows that the loss factor increased but the result was unsatisfactory compared to the loss factor 0.6 for K_ACM.

The result of the driving noise test showed little change in the insulation performance at the idle state, which is 27.5 Hz (Fig. 7(b)). On the other hand, the vibration was decreased by 2-3 dB compared to the conventional products at 70-80 Hz. The insulation property of ACM rubber in the vehicle at certain frequencies was shifted to a higher frequency due to complex factors. Table-4 lists the physical properties. The tensile strength and elongation was improved compared to conventional products but the hardness decreased. The changed details on the intercooler hose ingredient compound were the





(b)

Fig. 7. Analysis results of improved intercooler hoses: (a) loss factor (tan δ), (b) result of driving noise test

TABLE-4
MECHANICAL PROPERTIES OF THE INTERCOOLER HOSE

Properties	AR (Acrylic rubber)		
	HMC_AEM (conventional)	HMC_AEM (conventional)	HMC_AEM (improved)
Hardness (Hs)	69	64	61
Tensile strength (MPa)	13.0	8.2	9.4
Elongation (%)	280	190	280

same as those shown in Table-5. No change in the weight of the raw materials of rubber was observed, but ACM rubber, which had low viscosity, showed a 15 wt% increase in polymer portion, which is lower than that of the existing product, ML1+8 (125 ºC), 43 to 32. The carbon black content was decreased by 3 wt %, but the occupancy percentage of N330 in the compound of N330 and N774 increased. This was to prevent the decrease in elongation from using low viscosity rubber. Compared to the conventional compound, the plasticizer content was decreased by 2.5 wt% because of the mixing processability and the improvement in tensile strength.

TABLE-5
CHANGED DETAILS OF THE COMPOUND
(INTERCOOLER HOSE)

AR compound (%)	HMC_ACM (conventional)	HMC_ACM (improved)
Polymer	45	3+15 (low viscosity)
C/Black	44	41
Accelerator	0.5	0.8
Activator	0.7	0.7
Sulfur	0.5	0.5
Antioxidant	0.9	1.0
Plasticizer	6.0	3.5
Processing aid	2.4	2.5
Total	100	100

Conclusion

This study assessed a compound for improving the vibration insulation characteristics on the intercooler hose of the intake system and the heater hose of the heating system. The viscoelastic modulus of the materials and test vehicles were measured.

The storage modulus of the compound, which improved the vibration insulation of the heater hose, was 16.3 MPa, was *ca.* 44 % lower than that of the conventional value, 28.9 MPa. The evaluation results of driving car noise on the developed heater hose showed that the level of contribution was decreased by more than 2 dB compared to the conventional product at 1,000 Hz and over in the cold condition test.

The loss factor of the compound that showed improved vibration insulation of the intercooler hose was 0.5. The level was increased by *ca.* 25 % compared to that of the conventional value (0.42). The evaluation results of the driving noise test on the developed intercooler hose showed very little decreasing vibration in the idle range, but the value was 2-3 dB lower in the range of 70 to 80 Hz. No decrease in the physical properties of the developed heater and intercooler hose compounds compared to the conventional products was observed.

REFERENCES

1. C.W. Evans, Hose Technology, Applied Science Publishers Ltd. (1979).
2. C.M. Park, *Appl. Acoust.*, **63**, 775 (2002).
3. L.G. Hernández, L.I. Rueda, A.R. Díaz and C.C. Antón, *Polymer*, **33**, 3635 (1992).
4. G. Ramorino, D. Vetturi, D. Cambiaghi, A. Pegoretti and T. Ricco, *Polym. Test.*, **22**, 681 (2003).
5. J.E. Mark, B. Erman and F. Eirch, Science and Technology of Rubber, MRC (2001).
6. J.D. Ferry, Viscoelastic Properties of Polymers, Wiley, New York, edn. 2 (1970).
7. C.W. Evans, *Polym. Test.*, **7**, 309 (1987).