The Adhesion Properties of Stearic Acid-Loaded Rubber Compounds to Brass-Plated Steel Cords

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Abstract−The effect of stearic acid loading in rubber on the adhesion between rubber compounds and brass-plated steel cords was examined in respect to aging treatments and cure conditions. The adhesion interphase of a thin brass film/rubber compound containing stearic acid was investigated using an Auger electron spectrometer. The loading of stearic acid to rubber was not effective in the improvement of adhesion of rubber stock cured under optimum conditions, whereas it improved the adhesion property of premature cured samples by enhancing the physical property. High loading of stearic acid severely deteriorated the adhesion property, even at an unaged state due to the excessive formation of zinc sulfide. The loading of stearic acid did not affect the sensitivity of the rubber compound to humidity and thermal aging, but amplified the deterioration of adhesion when the rubber compound was subjected to salt solution aging, resulting in extremely poor adhesion. The effects of other ingredients and the aging treatment were also thoroughly examined.

Key words : Adhesion Interphase, Rubber-to-Brass Bonding, Stearic Acid, AES, Dezincification

INTRODUCTION

In automotive tires, steel cords have been used as reinforcing material for quite a long time. The performance of the tire is, to a large extent, dependent on the strength and durability of the adhesion between the rubber compounds and steel cords. The cords are conventionally plated with 200 nm brass which bonds the cords to the rubber of the tire during its vulcanization. Brass reacts with sulfur in the rubber compound during the curing process of tire manufacturing, forming an adhesion interphase between the rubber compound and steel cord [van Ooij, 1979, 1984]. An adhesion interphase with a sufficient thickness and a stable structure is essential for good adhesion [Kurbatov et al., 1991; Seo, 1997], so the optimization of vulcanization chemicals such as sulfur, accelerator and activator is a major concern in the aspects of the physical property of rubber [Ishikawa, 1984] and formation of an adhesion interphase [Hammer et al., 1994].

For reliable adhesion, the physical property of the rubber compound should be maintained sufficiently as well as the adhesion interphase. Adhesion may be ruptured at the rubber layer when the crosslinking density of rubber is insufficient. The rubber property is more significant at the thin rubber layer directly attached on the adhesion interphase, because a rupture in rubber layer proceeds at this layer. Therefore, the sufficient formation of copper and zinc sulfides at the adhesion interphase and the cross-linking density of rubber bulk or the thin layer must be simultaneously controlled to get properly crosslinked rubber attached to a properly formed adhesion interphase. Furthermore, the loading amount of activating chemicals such as zinc oxide and stearic acid, prompting

the crosslinking rate and density of rubber, brings about considerable influence on the adhesion property.

Stearic acid has been used as an activator with zinc oxide powder in rubber compounds to activate the accelerator and improve its effectiveness [Dogadkin and Beniska, 1958; Beniska and Dogadkin, 1959; Luyt, 1993]. Natural rubber compounds containing sulfur and organic accelerators usually require the presence of an adequate amount of zinc oxide and stearic acid to attain good crosslinking efficiency. Stearic acid acts with zinc oxide in the rubber compound as an activator, enhancing physical and adhesive properties. However, an excess loading of stearic acid is known to cause poor adhesion, though a decrease in physical property is not remarkable [van Ooij, 1981]. Therefore, it is helpful to find the reason for the poor adhesion due to excess loading of stearic acid to optimize the loading amount of stearic acid, resulting in an improved rubber property without any negative effects on adhesion.

The aim of this study is to show how stearic acid acts on the adhesion between rubber compounds and brass-plated steel cords. A simplified rubber compound was used in order to elucidate the effect of stearic acid loading more clearly, so adhesion promoters such as cobalt salt, resin, methylene donor and silica were not added. Physical and adhesive properties of rubber compounds with different loadings of stearic acid were investigated according to cure conditions and aging treatments. Adhesion interphases of thin brass film/rubber compounds were examined to discuss the effect of stearic acid loading on adhesion.

EXPERIMENTAL

1. Preparation of Rubber Stocks

Five rubber stocks with different loadings of stearic acid were prepared. Formulations for the masterbatch and final mixed com-

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Table 1. Rubber compound recipe

Material	Trade name	Manufacturer	Content (phr)
Masterbatch			
Natural rubber	SMP-10	Lee Rubber Co., Malaysia	100
Carbon black	N351	Lucky Co., Korea	45
Processing oil	A#2	Michang Co., Korea	5
Activator	ZnO	Hanil Co., Korea	10
Antioxidant	Kumanox-RD[1]	Monsanto Co., USA	1
Secondary added			
Activator	Stearic acid	Pyungwha Co., Korea	variable
Accelerator	Santocure MOR[2]	Monsanto Co., USA	0.7
Sulfur	Crystex HS OT 20	Akzo Co., The Netherlands	5

[1] 2,2,4-trimethyl-1,2-dihydroquinone.

[2] 2-(Morpholinothio)-obenzothiazole sulfenamide.

pounds are given in Table 1. Loading amounts of stearic acid were 0, 1.5, 3, 5 and 10 phr. All the rubber compounds were mixed as described in ASTM D3184-80 using an internal mixer (Banbury Mixer model 82, Farrel Co., U.S.A.). Ingredients for the masterbatch were incorporated for 10 min at a rotor speed of 40 rpm and discharged when the temperature reached 150 °C. After the masterbatch had been cooled to room temperature, the secondary mixing components were added and mixed for 5 min at 30 rpm, and then dumped at 90 °C. After mixing, the compounds were carefully remilled into flat sheets on a two-roll mill (model MKIII, Farrel Co. U.S.A.).

The rheocurves of the rubber compounds were obtained using a Monsanto Rheometer 100 at 160 °C according to ASTM D2084-93. The t_{90} time and maximum torque were calculated from those rheographs. Mooney viscosity was also measured by a Monsanto MV-200 machine following ASTM D1646-95a method.

Hardness of vulcanizates was measured using a Shore A durometer as described in ASTM D2240-91, and tensile properties were determined by a tensile tester (model 6021, Instron, U.S.A.) following the procedure described in ASTM D412-92.

2. Adhesion Test

T-test adhesion specimens of rubber compounds with different loadings of stearic acid were cured at 160 °C on a cure press, following the method suggested in ASTM D2229-93a. Three adhesive samples with different cure states were prepared in order to study the effect of the cure extent on adhesion. Over-cured samples were cured at four times of t_{90} time and under-cured samples for half of t_{90} time at 160 °C. Optimum cure time was determined as 1.1 times of t_{90} time. The brass-plated steel cord (Hyosung T&C, Korea) used had 4×0.28 construction in which four steel wires having a diameter of 0.28 mm were twisted. The specification of the cord, preparation of the adhesion specimens, aging treatment and tensile test for the evaluation of adhesion properties have been described in other papers [Jeon et al., 1998a, 1999a]. Salt solution aging using

15 % NaCl solution was performed to study the effect of stearic acid addition on the dezincification of the brass layer.

3. Depth Profile of Adhesion Interphase

Analyses of intact adhesion layers were carried out using brass film-on-glass adhesion samples. A thin brass film with the Cu/Zn ratio of 65/35 was sputtered onto a glass plate (Menzenglasser, 76×26 mm) using an RF Magnetron sputter for 70 s at 2×10^{-6} Torr. RF power was controlled to 400 W. The thickness of the thin brass film proved to be 100 nm using SEM (JEOL JSM 7400). A brass-on-glass plate was sandwiched between two rectangular sheets of green stock and cured at 160 °C in a pad mold. Preparation of interface analysis samples and details of the depth profile analysis by Auger electron spectrometer (Perkin-Elmer Phi 670) were discussed in our previous paper [Jeon et al., 1998b, 1999b, c].

Also, depth profiles of the pulled out cord surface, whose adhered rubber was removed by solvent swelling, were measured to discuss the role of stearic acid at the adhesion interphase.

RESULTS AND DISCUSSION

1. Cure Characteristics and Physical Properties of Stearic Acid-Loaded Rubber Compounds

The cure rates of rubber compound were varied with the loading amount of stearic acid as shown in Table 2. The t_2 time of rubber compounds showed a slight decrease with increasing the loading amount of stearic acid, while t_{90} time did not show any consistent trend. In the rubber compound with a low loading of 1.5 phr and 3.0 phr, t_{90} time was shortened by stearic acid loading, so the cure rate index (CRI) calculated from t_2 and t_{90} times increased. But t_{90} time increased for the rubber compound with 5 and 10 phr of stearic acid loading. The small loading amounts of stearic acid increased the CRI while the high loading of stearic acid showed a different result.

Torque also varied with the loading amount of stearic acid. Minimum torque decreased slightly with an increased loading amount of stearic acid, while maximum torque increased up to 5 phr of stearic acid loading. Mechanical crosslinking density, which can be deduced from the difference between maximum and minimum torque, does not show a consistent trend with the loading amount of stearic acid.

Table 2. Cure characteristics of rubber compounds with different amounts of stearic acid determined from their rheocurves[1]

Loading amount of stearic acid (phr)	Time (min)		CRI[2] (min⁻¹)	Torque (J)		
	t_2	t_{90}		min	max	Δ
0	2.4	12.3	10.1	1.98	6.07	5.09
1.5	2.1	9.4	13.7	1.68	6.43	4.75
3	2.0	9.7	13.0	1.64	6.45	4.81
5	1.9	10.5	11.6	1.51	6.77	5.26
10	1.8	12.5	9.3	1.38	6.35	4.99

[1] The rubber compounds were sheared in an oscillating disk type rheometer to ±1° and 1.67 Hz at 160 °C.

[2] CRI = $100/(t_{90} - t_2)$

Table 3. Result of Mooney viscometer test[1] for different loading amounts of stearic acid

Stearic acid (phr)	Time (min)		Torque (J)		
	t_5	t_{35}	initial	min	at 4 min
0	13.5	22.7	8.37	7.74	7.74
1.5	14.3	22.8	7.01	6.34	6.34
3	13.5	21.9	6.61	5.98	5.98
5	14.1	22.8	5.88	5.31	5.31
10	15.0	23.3	5.15	5.15	4.55

[1] The rubber compounds were sheared to 2 rpm at 125 °C.

Table 4. Unaged physical properties of rubber compounds with different loading amounts of stearic acid

Stearic acid (phr)	Hardness (Shore A)	Modulus (MPa)			T.S[1] (MPa)	E.B.[2] (%)
		50 %	100 %	200 %		
0	76	2.3	4.4	10.8	20.4	358
1.5	76	2.6	5.2	12.5	22.7	366
3	78	2.6	5.1	12.0	22.1	378
5	79	3.1	6.0	13.6	21.9	332
10	69	3.0	5.9	13.7	21.1	314

[1] Tensile strength.
[2] Elongation-at-break.

Table 5. Physical properties of rubber compounds with different loading amounts of stearic acid after thermal aging at 90 °C for 5 days

Stearic acid (phr)	Hardness (Shore A)	Modulus (MPa)			T.S.[1] (MPa)	E.B.[2] (%)
		50 %	100 %	200 %		
0	84	5.1	10.3	-	12.2	118
1.5	84	5.4	11.2	-	13.6	122
3	85	5.5	11.1	-	12.3	137
5	86	5.3	11.7	-	12.3	108
10	85	5.2	10.6	-	12.7	120

[1] Tensile strength.
[2] Elongation-at-break.

The variance of cure characteristics of rubber compounds with stearic acid loading suggests the roles of stearic acid as an activator and a masking agent. The increase of the cure rate for low loading is a well-known phenomenon due to the acceleration of crosslinking by stearic acid [Dogadkin and Beniska, 1958]. On the other hand, in the rubber compound with high loading, stearic acid reacts with zinc oxide and forms zinc stearate, resulting in masking the activating role of zinc oxide. Thus the cure rate slows for the rubber compound with a high loading of stearic acid. The maximum torque determined from the rheocurve increased with the increase in the loading amount of stearic acid up to 5 phr indicating its activating contribution. But the increase in torque was not significant. The increase of the maximum torque indicates the activating contribution of stearic acid.

Viscosity at a corresponding time for green compounds at 125 °C is listed in Table 3. The t_5 time and t_{35} time, indicating the onset of scorch time and the optimum cure time respectively, did not alter with stearic acid loading, while a slight delay is observed for the rubber compound with 10 phr of stearic acid. On the contrary, torque revealing viscosity of the rubber compound decreased with the increase in the loading amounts of stearic acid for all the cases initially, minimum and at 4 min. The rubber compound with a high loading of 10 phr showed very low torque, indicating a decrease in viscosity by about 60 % compared to that of stearic acid-free rubber compound. The decrease of viscosity arises because low molecular stearic acid acts as a lubricant among rubber molecules.

The physical properties of unaged vulcanizates are summarized in Table 4. Hardness, 50 % modulus, tensile strength and elongation at break increased with stearic acid loading up to 3 or 5 phr, but these properties decline for the rubber compound with 10 phr of stearic acid loading. 100 % and 200 % moduli showed a slight different trend from the above-mentioned behaviors, but the difference was not large enough to verify its significance. Thermal aging at 90 °C for 5 days led to a significant decrease in the physical properties of vulcanizates. However, the change of physical properties after thermal aging with the loading amount of stearic acid was similar to that of unaged properties as shown in Table 5.

The physical properties of vulcanizates examined in this study are slightly enhanced by the addition of stearic acid of up to 3 phr, indicating that the major role of stearic acid is to activate the accelerator but not to promote physical property. The improvement in the physical property by the loading of stearic acid is too
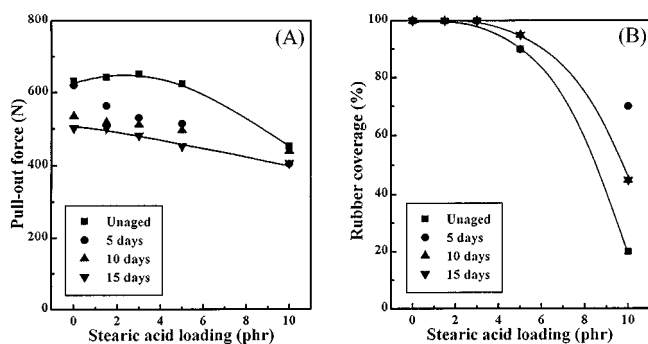
small to induce the improvement of the adhesion property. Excessive loading of stearic acid as 10 phr brought about deterioration of physical properties. Either low crosslinking density due to the loss of zinc oxide to form zinc stearate, or heterogeneous cure due to uneven mixing of heavy loading, may cause the low physical properties of the rubber compound.

2. Adhesion Properties of Stearic Acid-Loaded Rubber Compounds

The pull-out force and rubber coverage of stearic acid-loaded rubber compound before and after humidity aging are shown in Fig. 1. Aged adhesion properties after 5 and 10 days showed similar trends, so they were omitted for clarity. Unaged pull-out force increased slightly with stearic acid loading of up to 3 phr, but further increases in the loading amount of stearic acid led to a significant decrease. The pull-out force of the adhesion sample

Fig. 1. Adhesion properties of stearic acid-containing rubber compounds.
Humidity aging : 85 °C and 85 % relative humidity.

containing stearic acid of 10 phr loading was as low as two thirds of the stearic acid-free sample. Unaged rubber coverages of stearic acid-containing rubber compounds below 3 phr were high and the same irrespective of stearic acid, but rubber coverage was considerably low for the rubber compound with 10 phr stearic acid loading. The effect of stearic acid on the unaged adhesion property did not appear until 3 phr of loading. On the contrary, however, high loading of stearic acid brought about a severe deterioration in adhesion.

Humidity aging causes a decrease in adhesion properties [Lievens, 1986], but the decrease seemed not to be accelerated by the addition of stearic acid (Fig. 1). The difference in pull-out force between unaged and humidity aged samples was not considerably influenced by the loading amount of stearic acid. Rubber coverages of stearic acid-loaded adhesion samples up to 3 phr retained 100 % even after 15 days of humidity aging, whereas further increases in stearic acid loading led to a drastic decrease. The rubber compound with 10 phr of stearic acid showed very poor rubber coverage both before and after humidity aging. Therefore, the effect of stearic acid loading to the rubber compound is not remarkable on the humidity-aged adhesion property.

Thermally aged adhesion properties of stearic acid-containing rubber compounds are shown in Fig. 2. Poor adhesion properties of the rubber compound with a high loading of stearic acid were concomitantly observed even after thermal aging. The further deterioration of adhesive properties after thermal aging by stearic acid loading was not observed.

The adhesion properties of stearic acid-containing rubber compounds decreased drastically by salt solution aging as shown in Fig. 3. Although pull-out force and rubber coverage of stearic acid-free rubber compound was poor, the deterioration of adhesion of stearic acid-containing ones were severe. Especially, rubber coverages of stearic acid-contained rubber compounds were about 0-10 % after salt solution aging, regardless of their loading amounts. Loading of stearic acid caused severe deterioration of adhesion properties after salt solution aging, while there were no remarkable effects on those properties after humidity and thermal aging if the loading amount of stearic acid did not exceed 3 phr.

Adhesion properties vary with the cure conditions such as time and temperature. Generally, optimum cure time is determined as on the t_{90} time achieving 90 % crosslinking to avoid over cure. Fig. 4 shows the variation of adhesion properties with cure conditions.
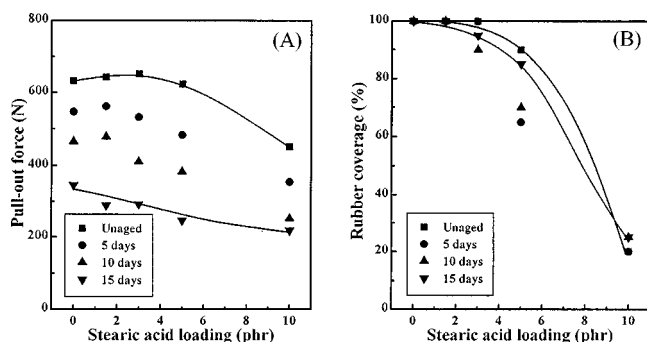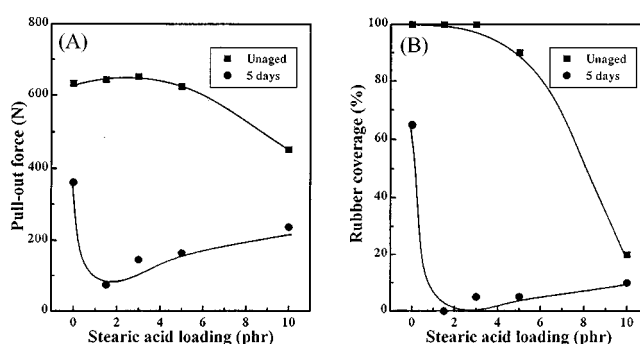

Fig. 3. Adhesion properties of stearic acid-containing rubber compounds.
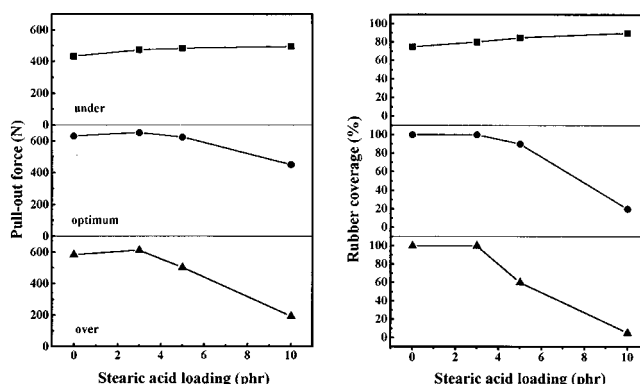　　Salt solution aging : 15 °C and 15 % NaCl aqueous solution.

Fig. 4. Variation of adhesion properties of stearic acid-containing rubber compounds with the extent of cure.

Cure time for under cure was set at 50 % of optimum cure time and that for over cure at 400 %. The pull-out force and rubber coverage of under cured adhesion samples showed a slight increase with the loading amount of stearic acid. Optimal and over-cured samples showed different behaviors. The effect of stearic acid loading on pull-out force and rubber coverage was not observed for the adhesion samples with low loading, but the decrease in the adhesion property was clear for those with loadings above 3.0 phr. The decrease in adhesion properties was significant for over-cured samples compared to optimally cured ones. Stearic acid may act as a positive ingredient for adhesion for the under-cured samples, but the adverse function with stearic acid loading is obvious for the optimally and over-cured samples especially those with high loading.

3. Characterization of Adhesion Interphase

The pull-out force and rubber coverage of adhesion samples varied with the loading amount of stearic acid in rubber compounds as well as cure conditions and aging treatments. The positive contribution of stearic acid to adhesion was small, but severe decreases in pull-out force and rubber coverage were observed with high loading, i.e., 10 phr. The extremely low rubber coverage indicates that the adhesion ruptured at the adhesion interphase and suggested that high loading of stearic acid gave adverse function on the adhesion interphase. The effect of stearic acid loading may influence the structure and composition of the adhesion interphase, resulting in poor adhesion at high loading.

Fig. 2. Adhesion properties of stearic acid-containing rubber compounds.
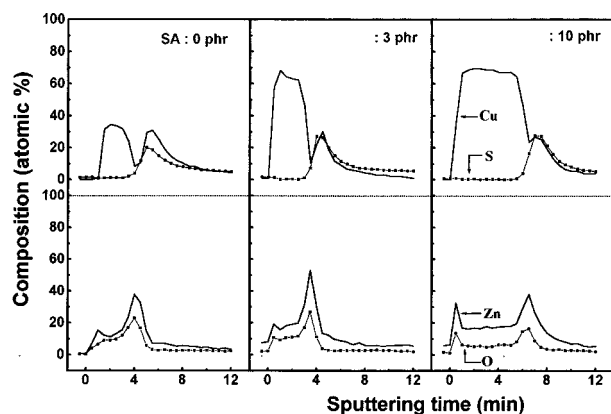　　Thermal aging : 90 °C.

Fig. 5. Depth profiles of copper, sulfur, zinc and oxygen at the unaged rubber compound/brass film adhesion samples with different loading amounts of stearic acid.

The cured adhesion sample composed of the rubber compound with stearic acid and brass film-on-glass gives some useful information on the adhesion interphase of rubber/brass film by AES investigated with sputtering from non-reacted brass surface to rubber bulk.

Depth profiles of copper, sulfur, zinc and oxygen of unaged rubber/brass film interphase are shown in Fig. 5. For clarity, the depth profiles of the rubber compounds with 1.5 and 5 phr have been omitted. Schematic shapes composed of an outer zinc oxide layer-non-reacted brass layer-adhesion interphase-rubber bulk were almost the same regardless of the loading amount of stearic acid. But the detailed shape and area of each peak varied with the loading level of stearic acid. The sulfur peak increased with stearic acid loading, while changes in the other peaks were not obvious. Stearic acid activates the accelerator which promotes crosslinking by generating activated sulfur, so the fast formation of sulfides at the adhesion interphase is expected with the high loading of stearic acid.

The rubber compound containing 10 phr of stearic acid showed poor adhesion property even at an unaged state. The large peak of sulfur observed may be a cause for the poor adhesion. Excessive growth of sulfides induces a rupture at the adhesion interphase due to the weak mechanical strength of sulfides. The poor rubber coverage of 10 % implies the generation of fatigue at the adhesion interphase.

During thermal and humidity aging treatments constituent materials of the adhesion interphase such as sulfides and oxides of copper and zinc grow and migrate. Simultaneously, a non-reacted brass reacts with sulfur in rubber or oxygen in air, resulting in the consumption of non-reacted brass layer and formation of sulfides and oxides. These materials are spread widely at the adhesion interphase and this wide spreading causes a deterioration of adhesion stability. The adhesion interphases of rubber/brass film spread widely after humidity aging as shown in Fig. 6. The second copper peak of stearic acid free sample spread widely to the rubber bulk after humidity aging, while it shows as a clear peak at the unaged state. Similar change in the second copper peak is observed at the adhesion interphase of the rubber compound with 3.0 phr of stearic acid. The rubber compound with 10 phr of stearic acid shows a different behavior. Most of the non-reacted brass layer is con-
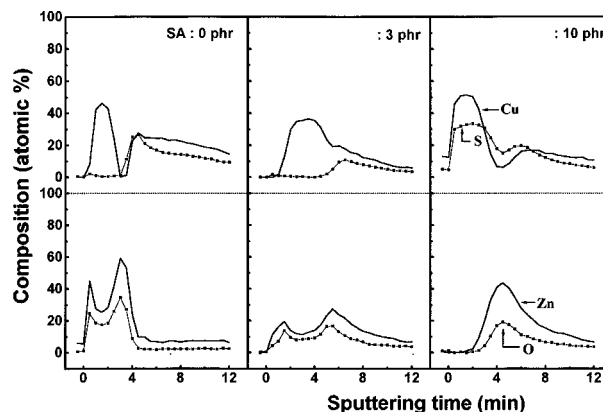
Fig. 6. Depth profiles of copper, sulfur, zinc and oxygen at the humidity aged rubber compound/brass film adhesion samples with different loading amounts of stearic acid.
Humidity aging: 85 °C and 85 % of relative humidity for 15 days.

sumed for 15 days of humidity aging. Unlike the other samples, the sulfur peaks are composed of two peaks. The copper metal in the non-reacted brass converted to sulfide with humidity aging. Furthermore the first zinc disappeared. Since water accelerates the dezincification of brass, fast formation of copper sulfide may be reasonable. Thus, over-growth of the sulfide layer and severe loss of metallic zinc at the adhesion interphase of the rubber compound with 10 phr of stearic acid causes poor adhesion.

The AES depth profiles of thermally aged rubber/brass film adhesion samples were recorded (Fig. 7), but there was no meaningful difference from those of unaged samples. The large sulfur peak was observed from that of the rubber compound with 10 phr of stearic acid showing poor adhesion.

The adhesion properties of rubber compounds containing stearic acid deteriorated severely with salt solution aging, even at the low loading of 0.5 phr. The AES depth profile may be helpful to deduce the cause of poor adhesion by stearic acid loading. But severe corrosion of the brass layer by salt solution made it impossible to get AES depth profiles after salt solution aging.
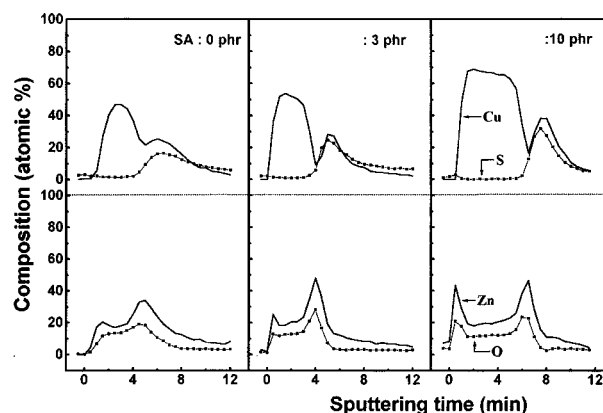

Fig. 7. Depth profiles of copper, sulfur, zinc and oxygen in the thermal aged rubber compound/brass film adhesion samples with different loading amounts of stearic acid.
Thermal aging : 90 °C for 15 days.

4. The Cause of Poor Adhesion with High Loading of Stearic Acid

The loading of stearic acid to rubber did not show any significant improvement in the unaged adhesion property between rubber compounds and brass-plated steel cords even when the loading amount was less than 3.0 phr, while adhesion properties were considerably low when the loading amount was more than 3.0 phr. Although stearic acid accelerated cure process resulted in the enhancement in physical properties of rubber, the improvement was too small to affect remarkably the adhesion property. Tensile strength and elongation at the break, indicating the fatigue resistance of the rubber, decreased slightly for the rubber compound with 10 phr of stearic acid, but the decrease was not so large as to cause extremely poor adhesion. Low rubber coverage even at the unaged state indicated that the poor adhesion was ascribed to the weakness of the adhesion interphase. The large formation of sulfides at the adhesion interphase with the high loading of stearic acid was due primarily to poor adhesion.

The adhesion properties of stearic acid-containing rubber compounds showed similar trends with the loading amount of stearic acid regardless of humidity or thermal aging treatments. The variance of adhesion property with stearic acid loading was not significant when its loading was below 3 phr. This means that poor adhesion due to high loading of stearic acid is mainly caused by the adhesion interphase formed in the curing process, although its growth and spread also influence the aged adhesion properties.

The obvious characteristic of the depth profile of the rubber compound with high loading of stearic acid was the plentitude of sulfide at the adhesion interphase. The excessive growth of sulfide with weak mechanical strength brings about its rupture resulting in cohesive failure. The large formation of copper sulfide during humidity aging may be due to severe dezincification by high concentrations of stearic acid. The loss of zinc activates remaining copper and the plenty of copper sulfide is formed as shown in Fig. 6.

On the contrary, deterioration of the adhesion property of the rubber compound containing stearic acid was severe with salt solution aging even though the loading amount of stearic acid was as low as 0.5 phr. Rubber coverage went from 100 % to about 0 % after only 5 days of salt solution aging. This large decrease in adhesion property suggests the severe damage to the adhesion interphase by salt solution aging. Stearic acid accelerates dissolution of the brass plated steel cord, resulting in extremely low rubber coverage. The large loading of stearic acid produces high crosslinking density, so the transfer of stearic acid and salt solution to the adhesion interphase is suppressed and the deterioration rate slowed. Severe deterioration of adhesion by salt solution aging shown in Fig. 3 is not usually observed for the rubber stock used for tire manufacture, because the so-called resinous bonding system, composed of resorcinol formaldehyde resin and methylene donor, protects the migration of stearic acid and water to the adhesion interphase by forming a high-molecular protective layer.

Though stearic acid was not effective for the improvement of the adhesion property of adhesion samples cured for optimum condition, the adhesion property of under-cured samples increased slightly by the loading of stearic acid. Stearic acid increased the cure rate and improved the physical property of rubber, resulting in better adhesion. But the loading of stearic acid did not induce any improvement for sufficiently cured adhesion samples, and high loading of stearic acid led to an excessive growth of sulfides at the adhesion interphase, resulting in poor adhesion.

CONCLUSIONS

The loading of stearic acid to rubber is not effective for the improvement in the adhesion between rubber compounds and brass-plated steel cords cured under optimum conditions, but stearic acid improves the adhesion property for insufficiently cured samples via the enhancement of physical property. Small loading amounts of stearic acid, i.e., 1.5 phr, do not show any negative influence before and after humidity or thermal aging. But the high loading of stearic acid, i.e., 10 phr, severely deteriorates adhesion property even without any aging treatments. An excessive formation of sulfide at the adhesion interphase by a high concentration of stearic acid brings about an extremely low adhesion property. The adhesion property of the rubber compound containing stearic acid is drastically deteriorated by salt solution aging, because the dissolution of zinc from brass by stearic acid causes severe damage to the adhesion interphase. Since stearic acid is usually added to obtain sufficient cure rate and the physical property for commercial rubber stock including sulfur and organic accelerator, its loading amount should be carefully controlled with consideration of its adverse function to adhesion.

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