Air Springs for Railways Available for Very Cold Environments

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The increase of urban population in recent years results in increased traffic, whereas the interest in environment and energy issues is growing. With the advantage of transporting a larger number of passengers with lower CO_2 emissions and consumption energy than automobiles and aircraft, railways are attracting international attention. Railway systems have been constructed around the world and being extended into cold regions such as European countries and China in recent years. Thus, Sumitomo Electric Industries, Ltd. has developed a new air spring for railways designed for cold region transportation. This new air spring successfully operates in very cold environments without sacrificing general properties. The key technology of this new product is the rubber compound formulation technology for diaphragm, which enables operation at a very low temperature with high flexibility.

Keywords: air spring, diaphragm, cold resistance, brittle temperature, ozone resistance

1. Introduction

The increase of urban population in recent years results in increased traffic, whereas the interest in environment and energy issues is growing. The advantage of transporting larger number of passengers with lower CO_2 emissions and energy consumption than automobiles and aircraft, railways have been attracting international attention.

In recent years, railways have been actively constructed especially in European countries such as France and Germany, and in East Asia such as China. Furthermore, new railway network construction has also been planned in other regions.

Sumitomo Electric Industries, Ltd. has been manufacturing and selling air springs for railway vehicles since 1958 and expanding its air spring business to China in the past few years, where the demand for construction of railway networks has been increasing.

Since the railway network has been extending to cold regions in China and eastern European countries in recent years, improved low temperature resistance is required by air springs. Particularly, at a lower temperature, the flexibility of rubber based material for the diaphragm of air springs decreases remarkably that results in the leakage of compressed air. Therefore, we have developed a new air spring that operates even at low temperatures by applying a new and ultra-flexible rubber-based material.

2. Structure and Manufacturing Process of Air Springs

As shown in **Figure 1**, the air spring installed between the railway vehicle body and the bogie is an important component that gives passengers comfort by absorbing vehicle body swings through a diaphragm inflated with compressed air.

Since the diaphragm is required to deform by following the movement of the bogie, the material used for the diaphragm is the laminate that consists of low air permeability flexible rubber material and reinforcement fabric.

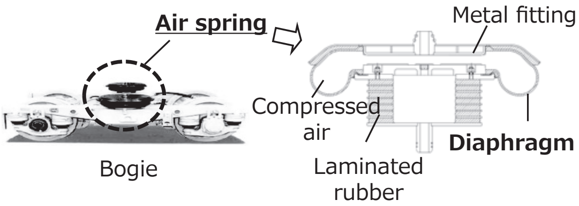

Fig. 1. Air spring for railway vehicle

The manufacturing process of a diaphragm consists of 5 steps as shown in **Figure 2**. The complex material is manufactured by 1) mixing raw material rubber and additives such as a vulcanizing agent,*1 2) sheeting, and 3) laminating the sheets on both sides of the reinforcement fabric. After that, the diaphragm is manufactured by 4) forming the complex material into a prescribed shape by laminating the complex sheet materials, and then 5) vulcanizing*2 the rubber material and adhering each other into a heated mold.

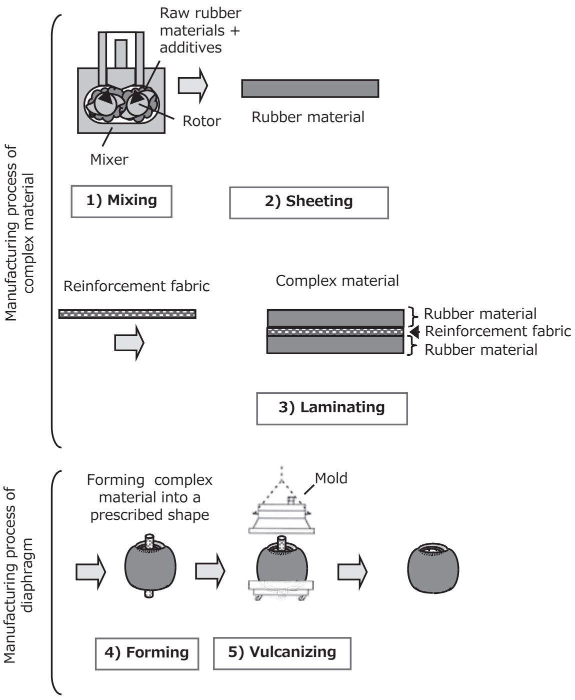

Fig. 2. Manufacturing process of diaphragm

3. Improvement of Low Temperature Properties of Rubber Material for Diaphragm

3-1 Target performances

In order to improve the low temperature property of the air spring, it is necessary to retain the high flexibility of the diaphragm at a lower temperature. We adopted the brittle temperature as the index of low temperature property, and decided the target value of brittle temperature at less than -60°C.(1) Brittle temperature is defined as when material loses flexibility and changes to be fragile and is broken by mechanical impact. The diaphragm is required to have ozone resistance and to keep the adhesion strength of laminates after repeated bending at the same time.(2) Furthermore, tackiness of the green sheet is also required to prevent the peeling of laminates in the aforementioned forming process of the complex sheet materials into a prescribed shape. The target performances of the rubber material are summarized in **Table 1**.

Table 1. Target performances

Properties		Target
Cold resistance	Brittle temperature [°C]	≦ -60
Ozone resistance (Dynamic, Ozone concentration: $100_{\pm 5}$ pphm, Elongation: 0–5%, Exposure time: 144 h)		No crack
Adhesion at the laminated surface of vulcanized rubber [kgf/25 mm]		≧ 10
Formability	Tackiness at the laminated surface of unvulcanized rubber [kgf/25 mm]	≧ 0.4

3-2 Material design

Rubber materials based on chloroprene rubber exhibiting excellent ozone resistance have been used in the diaphragm of current air springs.(3) However, it is anticipated that the low temperature property of this material is not enough when operated at a lower temperature. This is because the glass transition temperature*3 of chloroprene rubber is -43 to -45°C. Thus, we tried to use other raw rubber materials having lower glass transition temperatures than chloroprene rubber without sacrificing ozone resistance.

Table 2 shows glass transition temperature and ozone resistance of various raw rubber materials.(4)-(6) Ethylene-propylene-diene rubber, butyl rubber, and silicone rubber have excellent ozone resistance as well as chloroprene rubber, however, other properties such as adhesion are not good enough for diaphragm manufacturing. Since the improvement of adhesion by blending each of them with chloroprene rubber is not promising, we excluded them as candidates.

Table 2. Glass transition temperature and ozone resistance of various raw rubber materials

Raw rubber material	Glass transition temperature [°C]	Ozone resistance
Chloroprene rubber	-43 – -45	○
Natural rubber	-69 – -79	×
Ethylene-propylene-diene rubber	-60 – -69	○
Butyl rubber	-67 – -75	○
Butadiene rubber	-75 – -110	×
Silicone rubber	-112 – -132	○

On the other hand, the glass transition temperature of butadiene rubber is extremely low (-75 to -110°C) but ozone resistance is inadequate. Then, we considered that the compatibility of low temperature property, adhesion and ozone resistance would be achieved by the micro-dispersion of butadiene rubber into chloroprene rubber to make a polymer alloy structure*4 where the chloroprene rubber acts as a matrix and butadiene rubber as a domain. It is expected that the polymer alloy would prevent the propagation of micro-crack by the

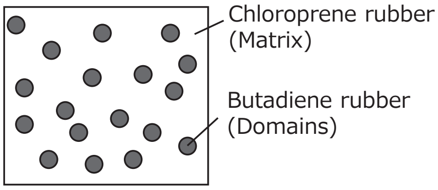

Fig. 3. Assumed diagram of polymer alloy

micro-dispersed domain even if a micro-crack occurs by ozone attack at butadiene as domains. The assumed diagram of polymer alloy is illustrated in **Figure 3**.

3-3 Development of rubber material

We investigated the micro-dispersing process of chloroprene rubber and butadiene rubber based on the previously mentioned material design. However, adhesion of the laminates was inadequate due to low tackiness of the rubber material. In order to solve this problem, we tried to blend a small amount of natural rubber having excellent tackiness while the glass transition temperature is higher than butadiene rubber. The blending ratio of chloroprene rubber was determined by monitoring the ozone resistance, and the ratio of butadiene rubber and natural rubber was optimized considering the balance of brittle temperature, adhesion and tackiness.

Figure 4 shows the relationship between the ratio of butadiene rubber/natural rubber and each property. The compatibility of brittle temperature, adhesion and tackiness was achieved by determining the ratio of butadiene rubber/natural rubber within a prescribed range. The property of the rubber compound developed is summarized in **Table 3**.

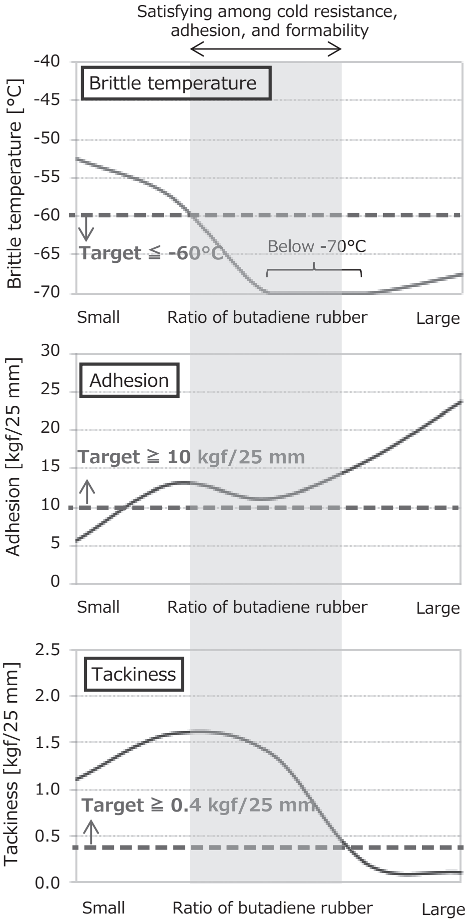

Fig. 4. Relationship between the ratio of butadiene rubber and each property

Table 3. Property of the developed rubber compound

Properties		Target	The developed rubber compound
Cold resistance	Brittle temperature [°C]	≦ -60	○
Ozone resistance		No crack	○
Adhesion at the laminated surface of vulcanized rubber [kgf/25 mm]		≧ 10	○
Formability	Trackiness at the laminated surface of unvulcanized rubber [kgf/25 mm]	≧ 0.4	○

4. Performance Evaluation of Air Spring

We proceeded with the performance evaluation tests of the trial manufactured air spring by applying the new rubber compound we had developed at both room temperature and lower temperature.

The test results are shown in **Table 4**. The lower temperature tests were carried out in a low-temperature thermostat bath and the diaphragm was inflated by compressed air of 600 kPa inside. In the pressure test and airtightness test, we confirmed that any deflation did not occur and the amount of air leakage satisfied the target value even at a lower temperature. Moreover, we also confirmed that any air leakage was not observed when the air spring was deformed in a vertical and a horizontal direction.

Table 4. Results of the performance evaluation tests of the air spring (inner pressure: 600 kPa)

Test [Target]	At room temperature	At a very low temperature
Pressure test [No deflation]	○ No deflation	○ No deflation
Airtightness test [Air leaked amount < 9.8 kPa]	○ 2.2 kPa	○ 1.8 kPa
Deformation test (vertical/horizontal direction) [No air leakage]	○ No air leakage	○ No air leakage

Figure 5 shows the temperature dependence of the spring constant measured when the air spring was deformed in a horizontal direction in which the spring shows a larger displacement. Spring constant is an index of a hardness of an air spring, and its temperature dependence is desirably smaller. A difference of 15%, which is the largest difference of the spring constants between the two different springs, is achieved at low temperatures.

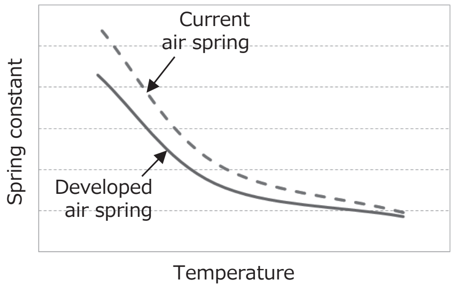

Fig. 5. Temperature dependence of spring constant (horizontal direction)

5. Conclusion

We have succeeded in developing a new rubber material showing improved flexibility at a lower temperature. The air spring using an improved rubber diaphragm is suitable for railway vehicles running in very cold environments.

This air spring achieves a pressure resistant performance and airtightness performance also at lower temperatures. In the near future, it is expected that this new air spring will be widely adopted for global railway networks including those in very cold regions.

Technical Terms

∗1 Vulcanizing agents: Compounding agents for rubber to vulcanize raw rubber materials. Sulfur is generally used as a vulcanizing agent.

∗2 Vulcanize: In order to make three-dimensional intermolecular cross-linking by heating, the vulcanizing agents such as sulfur and peroxide are formulated in a rubber composition. This molecular structure realizes the elasticity of restoring to the original shape when expanded.

∗3 Glass transition temperature: Temperature where raw rubber material changes to a glass-like state when cooling. Although raw rubber materials show high flexibility at room temperature, molecular motion of the main chain of polymer is suppressed at lower temperature, thereby deteriorating flexibility to be in a glass-like state. Glass transition temperature is determined by the molecular structure of raw rubber material.

∗4 Polymer alloy: Micro-dispersion of more than two kinds of immiscible raw rubber materials with thermodynamically stable matrix-domains phase structure.

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