Development of Halogen-Free Type Heat-Adhesive Small-Diameter ABS Sensor Cable

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Anti-lock brake system (ABS) has been installed as a basic system for supporting safety driving of automobile since 2000. SEI has developed the heat adhesive ABS sensor cable that contributes to the reduction of process cost for wheel speed sensor unit production. The heat-adhesion ABS cable adheres to the housing material during the injection molding process to make a waterproof seal between the cable and the sensor. SEI is promoting the use of environmentally friendly halogen free wire and cables in automotive wire harnesses. Corresponding to this program, SEI has succeeded in developing the halogen free small diameter heat adhesive ABS sensor cable.

1. Introduction

Anti-lock brake system (ABS) is installed on most new vehicles manufactured since year 2000 as standard equipment that acts as a basic system for supporting safety driving of automobile. An ABS consists of an electronic control unit (ECU), four speed sensors (one for each wheel), and two or more hydraulic valves mounted on a brake circuit. The ECU constantly monitors the rotary speed of each wheel and controls the hydraulic valves to prevent the wheels from being locked during the braking process. The wheel speed sensors each installed near a wheel are exposed to severe external environment, such as splashing water and ice accretion, and so a fully waterproof seal must be created between the sensor and an ABS cable.

In the conventional wheel speed sensor manufacturing process, the following two steps have been required: (1) Installation of a mechanical seal to waterproof the cable, and (2) injection molding of resin around the wheel speed sensor.

Sumitomo (SEI) Electronic Wire, Inc. had developed a heat-adhesive ABS cable that thermally adheres to the molding resin in the injection molding process and thus creates a waterproof seal between the cable and the sensor, as shown in **Fig. 1** (1). The heat-adhesive ABS cable contributes not only to the reduction of steps in the manufacturing process but also to the reduction of production costs, and it has already been adopted by several users.

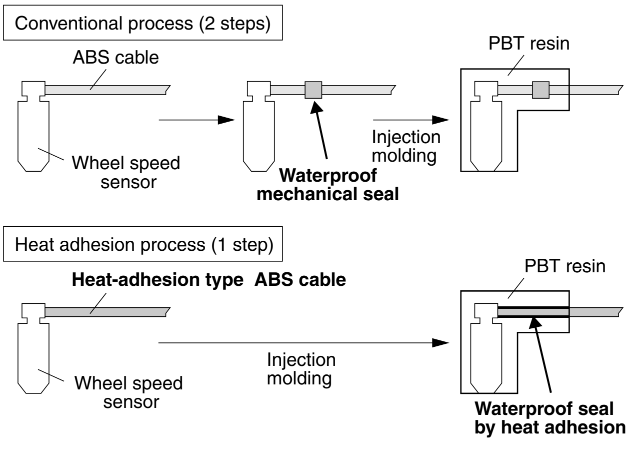

Fig. 1. Process for connecting ABS cable and wheel speed sensor

The wires and cables for automotive use must satisfy the flame retardant property specified in a standard determined by the Japan Automobile Standards Organization (JASO), which had developed from the Society of Automotive Engineers in Japan. To reduce environmental burden, Sumitomo (SEI) Electronic Wire has been promoting the use of halogen-free flame-retardant wires and cables in its automotive wiring harnesses. As a part of this effort, the Company has developed a halogen-free type of the heat-adhesive smaller-diameter ABS cable in order to promote further use of halogen-free cable jackets and at the same time minimize production costs.

2. Development of halogen-free heat-adhesive ABS cable

2-1 Heat-adhesive ABS cable

The construction of an ABS cable, which connects a wheel speed sensor with an ECU, is illustrated in **Fig. 2**. A twisted pair of insulated wires is jacketed with polyurethane elastomer that is cross-linked by electron beam irradiation. The reason why polyurethane elastomer is used as a jacketing material is that it features high levels of both flexibility and mechanical strength. The purpose of cross-linking by electron beam irradiation is to improve the resistance to heat, abrasion, and hydrolysis of the material (2).

The heat-adhesive ABS cable, on the other hand, is jacketed with a polymer alloy comprising of polyurethane elastomer and polyester elastomer.

Figure 3 is the reflection scanning electron microscope (SEM) image of the phase structure of a polyurethane/polyester polymer alloy developed and used by Sumitomo (SEI) Electronic Wire. A polyester elastomer, which is the phase matrix of the alloy, thermally adheres to polybutylenetelephthalate (PBT) or polyamide generally used as the molding resin for wheel speed sensors, and a polyurethane elastomer, which constitutes the domains dispersed in the phase, improves mechanical strength and abrasion resistance.

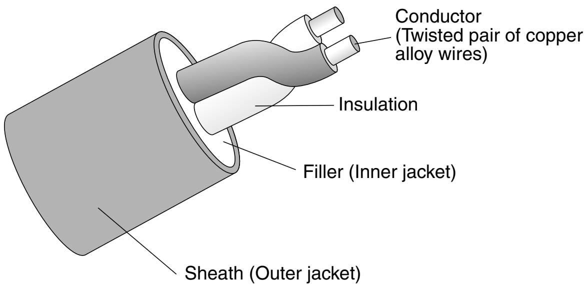

Fig. 2. Construction of ABS cable

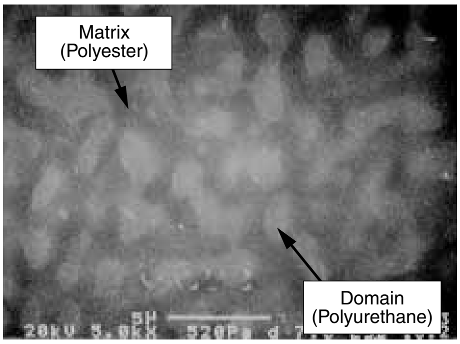

Fig. 3. Phase structure of polyurethane/polyester alloy

2-2 Flame retardance of halogen-free polymer materials

Polyurethane and polyester elastomers are combustible resins, and cables jacketed with these resins do not pass the flame test. Therefore, it is necessary to provide flame retardance to polyurethane elastomer and polyester elastomer.

There are several methods for providing flame retardance to polymeric materials, such as addition of flame retardant and reduction of the amount of combustiblematerials by adding inorganic fillers. Representative examples of halogen-free flame retardants that do not contain halogen elements like chlorine or bromine are: i) Metal hydroxide such as aluminum hydroxide and magnesium hydroxide, ii) phosphorous-based flame retardant such as condensed ester phosphate, and iii) nitrogen-containing flame retardant such as melamine salts (3).

As previously mentioned, since the injection molding of PBT or polyamide is used in the process for manufacturing wheel speed sensors, it is necessary to select a heat resistant flame retardant that does not decompose at the injection molding temperature from 260 to 300 deg. C. The thermal gravimetric analysis (TGA) results of major flame retardants are shown in **Fig. 4**. Nitrogen-containing flame retardant, such as melamine salts, has the same heat resistance as bromide containing flame retardant. Therefore, the nitrogen-containing type was selected as the flame retardant suitable for addition to the outer jacket.

Figure 5 is the transmission electron microscope (TEM) image of the polyurethane/polyester alloy containing nitrogen-based flame retardant. It was confirmed that polyester forms the matrix and polyurethane forms the domains, showing a phase structure similar to that in **Fig. 3**.

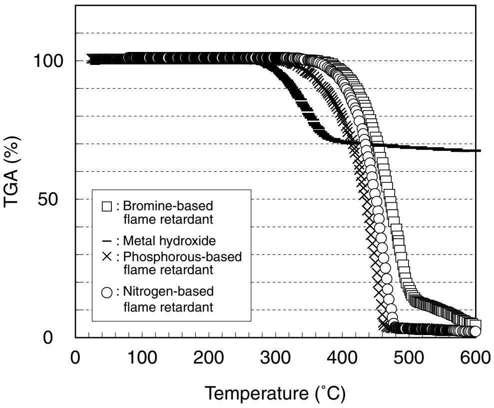

Fig. 4. TGA of representative flame retardants

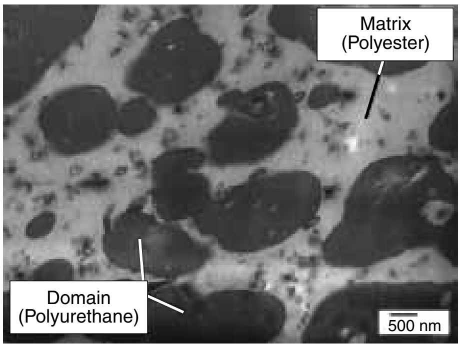

Fig. 5. Phase structure of polyurethane/polyester alloy containing flame retardant

2-3 Design and trial manufacturing of halogen-free type heat-adhesive ABS cable

The Company manufactured a prototype halogen-free heat-adhesion ABS cable that consists of a twisted pair of HFSSX wires having halogen-free flame-retardant cross-linked polyolefin insulation (conductor: 0.25 sq mm, insulation OD: 1.4 mm), surrounded by a filler layer (OD: 3.4 mm) made of flexible polyolefin resin, and by an outer jacket (OD: 4.0 mm) made of the polyurethane/polyester alloy containing flame retardant.

Figure 6 depicts the relation between the burning time of the cable in the horizontal flame test and the amount of flame retardant contained in the outer jacket. This result shows that more than 15 vol% flame retardant should be contained to satisfy the burning time specification of within 30 seconds.

To evaluate the heat-adhesion property of the outer jacket material to molding resin, a hot-pressed sample of the cross-linked polyurethane/polyester alloy sheet united with a PBT plaque was prepared and then subjected to a peeling test, as shown in **Fig. 7**.

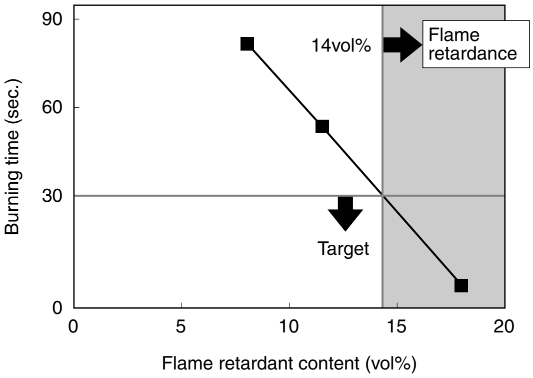

Fig. 6. Burning time vs flame retardant content

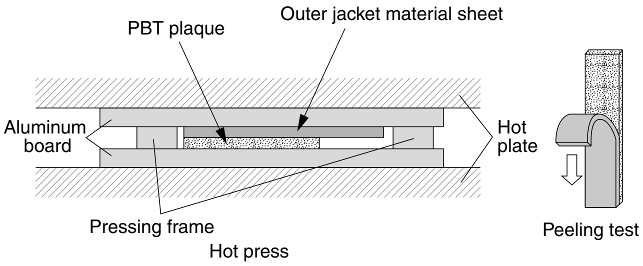

Fig. 7. Evaluation of heat adhesiveness

Figure 8 depicts the relation between the outer jacket's peel strength and flame retardant content, showing that the peel strength of the outer jacket decreased along with the increase of the amount of flame retardant contained in it. Since the current jacket material containing halogen-based flame retardant showed a peel-strength of more than 40 N/cm in the cohesion failure mode, it was found that flame retardant content should be less than 6 vol% in the halogen-free jacket formulation.

From these results, it was revealed that flame retardance cannot be achieved together with heat adhesiveness by simply adding flame retardant to the outer jacket material.

2-4 Flame retarding treatment to filler layer

Therefore, to balance flame retardance with heat adhesiveness, it is necessary to provide flame retardance to both the outer jacket and the filler layer. Flame retardance can be provided to the flexible polyethylene filler by adding metal hydroxide, which is an effective flame retardant for polyethylene.

Figure 9 shows the horizontal flame test result for the prototype cable under conditions where the flame retardant content in the outer jacket was fixed at 6 vol% but that in the filler layer varied. The burning time decreased with the increase of the amount of metal hydroxide. The cable satisfied the burning time specification of within 30 seconds when the metal hydroxide content in the filler was more than 18 vol%, achieving both flame retardance and heat adhesiveness.

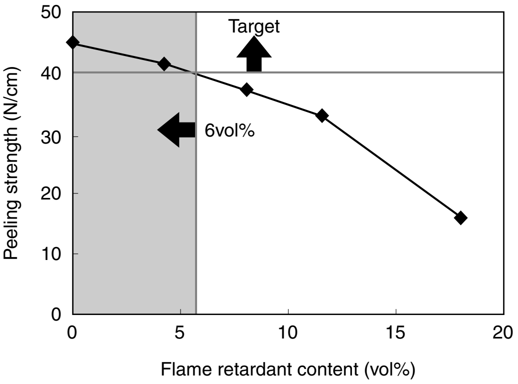

Fig. 8. Peeling strength vs flame retardant content

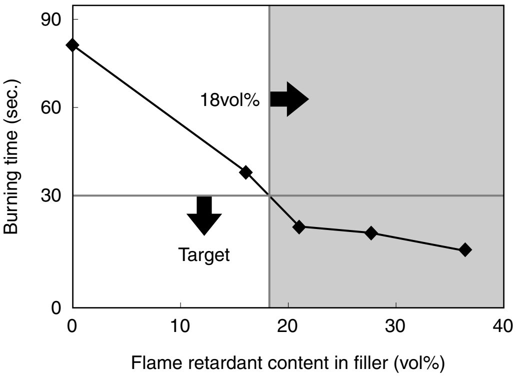

Fig. 9. Burning time vs flame retardant content in filler

2-5 Evaluation of prototype cable

The general properties of the prototype cable are listed in **Table 1**. The cable satisfied the specifications for oil resistance, heat resistance and hot-water resistance. However, the result of the abrasion resistance test (abradant: sandpaper) was that the cable withstands the abrasion up to a distance of 12.4 m, not satisfying the specification of 20 m or more.

2-6 Improvement of abrasion resistance

Since the cable having flame retarding capability only in its outer jacket was abrasion resistant over an

Table 1. Specifications and general properties of prototype cable

Item	Parameter		Unit	Result	Specification
Insulation	Tensile strength		MPa	16.5	10.3 ≦
	Elongation		%	190	150 ≦
Sheath	Tensile strength		MPa	18.5	14.7 ≦
	Elongation		%	520	100 ≦
Oil resistance	Heated at 50°C for 20 hr and winded		–	No cracking or melting	No cracking or melting
Heat resistance I	Heated at 136°C for 168 hr and winded		–	Withstood 1000V AC	Withstand 1000V AC
Heat resistance II	Winded (self-diameter winding) and heatedat 200°C for 30 min.		–	No cracking or melting	No cracking or melting
Low temperature resistance	Cooled at -45°C for 3 hr and winded		–	Withstood 1000V AC	Withstand 1000V AC
Hot water resistance	At 100°C for 168 hr	Tensile strength	Retention ratio %	74	30 ≦
		Elongation	Retention ratio %	72	70 ≦
Flame retardance	JASO horizontal flame test		Sec.	5	≦30
Heat adhesiveness	To PBT at 230°C		N/cm	46	30 ≦
Abrasion resistance	At 4.4 N load		m	12.4	20 ≦

abrasion distance of 25 m, it was confirmed that the lack of abrasion resistance in a cable can be attributed to the lack of abrasion resistance in its filler.

Figure 10 depicts the stress-strain curve of the filler used in the prototype cable. As the area under the stress-strain curve correlates with the fracture energy of the material, it was considered that increasing the area under the stress-strain curve is effective for improving the abrasion resistance of the filler layer. The following two methods were studied: (1) Use of higher molecular weight flexible polyolefin to improve tensile strength and elongation, and (2) combination of flexible polyolefin and metal hydroxide to increase cohesive energy.

Figure 11 depicts the stress-strain curves of (1) a filler containing higher molecular weight flexible polyethylene and (2) a filler containing a silane coupling agent. It was found that by using a filler containing both higher molecular weight flexible polyolefin and a silane coupling agent, the area under the stress-strain curve becomes approximately two times larger than the original one. A prototype cable manufactured using this new filler withstood a sandpaper abrasion distance of 23 m, showing an improved abrasion resistance and satisfying the abrasion resistance specification.

2-7 Evaluation of developed cable

The general properties of the developed cable evaluated in accordance with the JASO standard are listed in **Table 2**. It was verified that the cable satisfies all the specifications. This newly developed halogen-free heat-adhesive ABS cable has been confirmed by a user as being equivalent to the current heat-adhesive ABS cable in reliability properties, including resin moldability against the cable and the waterproofness of the molded item. This new cable has been used by a user since year 2005.

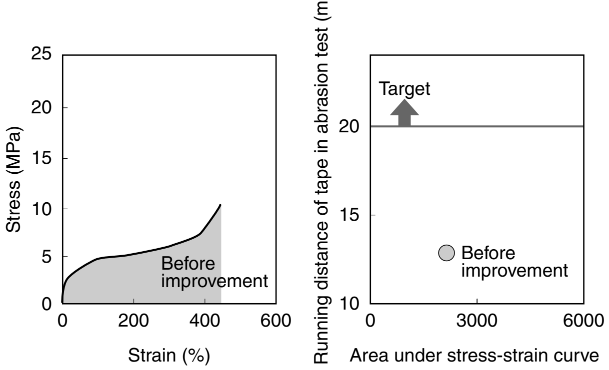

Fig. 10. Relation between filler's stress-strain curve and abrasion property

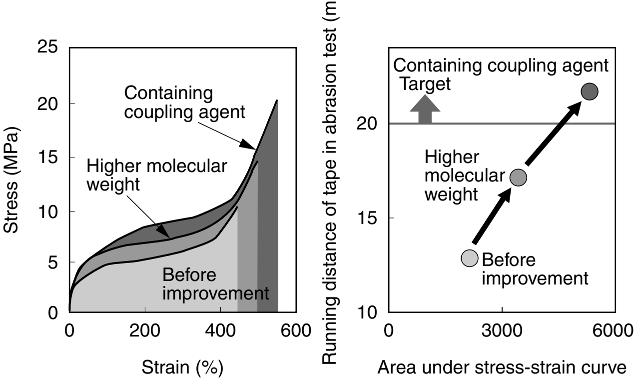

Fig. 11. Relation between filler's stress-strain curve and abrasion property

Table 2. Specifications and general properties of developed cable

Item	Parameter		Unit	Result	Specification
Insulation	Tensile strength		MPa	16.9	10.3 ≦
	Elongation		%	189	150 ≦
Sheath	Tensile strength		MPa	17.6	14.7 ≦
	Elongation		%	469	100 ≦
Oil resistance	Heated at 50˚C for 20 hr and winded		–	No cracking or melting	No cracking or melting
Heat resistance I	Heated at 136˚C for 168 hr and winded		–	Withstood 1000V AC	Withstand 1000V AC
Heat resistance II	Winded (self-diameter winding) and heatedat 200˚C for 30 min.		–	No cracking or melting	No cracking or melting
Low temperature resistance	Cooled at -45˚C for 3 hr and winded		–	Withstood 1000V AC	Withstand 1000V AC
Hot water resistance	At 100˚C for 168 hr	Tensile strength	Retention ratio %	65	30 ≦
		Elongation	Retention ratio %	74	70 ≦
Flame retardance	JASO horizontal flame test		Sec.	5	≦30
Heat adhesiveness	To PBT at 230˚C		N/cm	43.8	30 ≦
Abrasion resistance	At 4.4 N load		m	23	20 ≦

3. Conclusion

This paper has reported on the development of the new heat-adhesive small-diameter ABS cable. The newly developed cable is free of halogen and satisfies specifications for flame retardance and also for heat adhesiveness to molding resin, although the cable has a diameter of 4.0 mm, it satisfies cable reliability properties such as oil resistance, hot water resistance, and abrasion resistance as well. It was confirmed in the reliability test conducted by a user as being equivalent to the conventional cable and has been commercially used since 2005. Use of this new cable is not limited to ABS sensor, and is expected to expand into a new application area of automotive sensor for the purpose of providing waterproofness by heat adhesion.

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