Development of In-Vehicle Flexible Flat Cables

Yutaka FUKUDA*, Hiroshi HAYAMI, Kensuke NAKAMURA, Tatsuji OKU and Tatsuo MATSUDA

Multi-core flexible flat cables have been commonly used for electric wiring to electronic appliances. Along with the increase of electronic equipment installation in automobiles, in-vehicle flexible flat cables have found wider applications, taking the advantage of the flat shape for high-density and compact wiring. Sumitomo Electric has developed and manufactured various kinds of flexible flat cable products for electronic appliances. Based on its experience and technical know-how in this field, Sumitomo Electric has succeeded in developing new in-vehicle flexible flat cables featuring higher reliability even when applied in severe conditions such as hot-water immersion (85°C × 35 days), high-humidity and high-temperature exposure (85°C and 85% RH × 1000 hours, 125°C × 3000 hours).

Keywords: flexible flat cable, automotive use, ISO, JASO, UL standards

1. Introduction

In recent years, automobiles are increasingly equipped with electronic devices such as navigation and radar detection systems. The use of cables designed to supply power and transmit information to these electronic devices has also increased, and is expected to increase further. Meanwhile, for reasons relating to vehicle weight reduction and downsizing, in-vehicle electronic devices have been modularized; in other words, the main unit, peripheral equipment and cables, have been integrated. The use of flexible flat cables, thin and high in wiring density, is increasing.

In the electronics sector, Sumitomo Electric Industries, Ltd. has developed many flexible flat cables meeting various customer requirements. On the basis of the material and manufacturing technologies we developed in that sector, we have commercialized in-vehicle flat harnesses incorporating flexible flat cables for steering systems, roofs and doors.

This report provides detailed information on the development of high-performance, high-reliability flexible flat cables designed for use in harsher in-vehicle environments.

2. Development of In-Vehicle Flexible Flat Cables

2-1 In-vehicle flexible flat cables

Figure 1 shows a flat cable structure. This flat cable is manufactured by laminating rectangular conductors, running parallel with one another, between two adhesive-coated base films (insulating tapes). The cable's notable feature is its thinness, ranging from 100 to 300 μm. The insulating tape base film may be a polyethylene terephthalate (PET), polyimide (PI) or other plastic film, depending on use or characteristic requirements. PET is most widely used, due to its advantages in mechanical and electrical characteristics, and cost effectiveness. As regards adhesive, polyester-based types are quite often used, since they are excellent in adhesion with conductors. An anchor coat is provided at the interface between PET film and polyester adhesive, for increased adhesive reliability.

Moreover, supporting tapes are attached to cable ends for simple insertion into connectors.

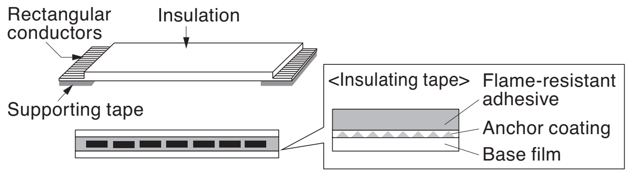

Fig. 1. Structure of flexible flat cable

Sumitomo Electric's in-vehicle flexible flat cables have been developed in compliance with Japanese Automotive Standards Organization (JASO) standards and International organization for Standarization (ISO) standards for insulated wires. **Table 1** shows the specifications of great importance contained in these standards. Flexible flat cables are required to meet heat resistance requirements such that after 3,000 hours of heat aging at their rated temperature, they do not exhibit electrical breakdown when subjected to application of a specified voltage in water. Regarding the low-temperature resistance of flexible flat cables, the insulation shall not break off when, at −40°C, the cable is wound around a mandrel of a specified diameter.

In the hot-water resistance test, after immersion in hot water for 35 days at 85°C, the flexible flat cable shall not show electrical breakdown when 1 kV is applied to it for 1 min in water.

Furthermore, depending on the intended use, flexible flat cables must comply with Underwriters Laboratories Inc. (UL) standards in addition to JASO and ISO standards, and provide long-term moist heat resistance (durability under moist and hot conditions). UL standards are stricter than JASO and ISO standards in terms of flame resistance requirements. In the flame test specified in JASO or ISO standards, the test cable is placed in a horizontal position or at an angle of 45° over a burner for ignition. In contrast, UL standards specify the VW-1 test, in which the test cable is placed in a vertical position over a burner for ignition. Accordingly, UL standards require a higher level of flame resistance than JASO and ISO standards.

Regarding moist heat resistance, flexible flat cables are required to exhibit no electrical breakdown when, after exposure to 60°C and 95% RH or 85°C and 85% RH for 1000 h, they are subjected to the application of 1 kV for 1 min in water.

Taking these market requirements into consideration, we aimed to develop flexible flat cable products that would meet a wide range of customer requirements for in-vehicle applications. We set development targets to meet the specifications shown in **Table 2**.

Table 1. Key requirements for in-vehicle (JASO and ISO standards) and electronics (UL standards) applications

	In-vehicle application (JASO and ISO)	Electronics application (UL)
Heat resistance	125°C for 3000 h, followed by dielectric strength test in water. No electrical breakdown.	136°C for 7 days, followed by dielectric strength test in air
Moist heat resistance	85°C and 95% RH for 120 h, followed by dielectric strength test in water. No electrical breakdown.	Not required
Low-temperature resistance	Winding test at −40°C for 4 h. Insulation shall not break off.	Winding test at −20°C for 1 h. Insulation shall not break off.
Hot water resistance	35 days in hot water at 85°C, followed by dielectric strength test in water. No electrical breakdown.	Not required
Flame resistance	Horizontal flame test 45° angle flame test	Vertical flame test (VW-1)

Table 2. Primary development targets

Item	Test condition	Target
Heat resistance	125°C 3000 h	Dielectric test at 2 kV for 1 min in water. No electrical breakdown.
Moist heat resistance	60°C, 95%RH × 1000 h 85°C, 85%RH × 1000 h	Dielectric test at 2 kV for 1 min in water. No electrical breakdown.
Low-temperature resistance	40°C for 8 days, followed by 180° bending	Insulation shall not break off.
Hot water resistance	85°C for 35 days in hot water	Dielectric test at 2 kV for 1 min in water. No electrical breakdown.
Flame resistance	Vertical flame test (VW-1)	Pass (Flame duration: 60 s max.)

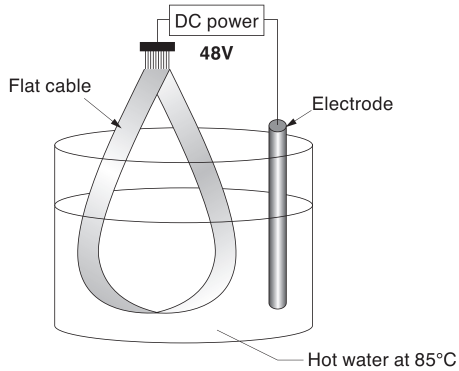

Fig. 2. Hot water test method

2-2 Development of new adhesive

Under a hot and humid environment, the polyester adhesives, commonly used to apply insulating tapes in forming flexible flat cables, are subject to decrease in molecular weight due to hydrolysis of the ester group in the main chain. The reaction mechanism is shown in **Fig. 3**. Consequently, the bond between adhesive and conductors diminishes and the adhesive electrical characteristics degrade. Various compounding agents have been developed to retard hydrolysis of the ester group, but these are not satisfactory, given the moist heat and hot water resistance levels presently set as the development targets. It was therefore necessary to develop an adhesive made from a resin whose molecular structure resists hydrolysis.

Our solution was to develop an adhesive using polyolefin resin as a base resin, since polyolefin resin is excellent in terms of electrical characteristics, heat resistance and low-temperature resistance, and is inherently free from hydrolysis.

However, since polyolefin resins, such as polyethylene and polypropylene, do not adhere to the conductors, the polyolefin resin's molecular structure was partially chemically modified and a functional group was introduced to enable adherence to the conductors and to meet the specifications for adhesive strength.

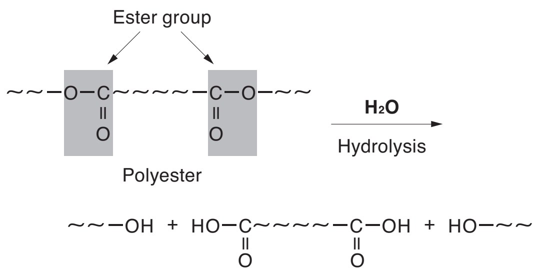

Fig. 3. Hydrolysis of polyester

When tested in a harsh environment of moist heat at 85°C and 85% RH for an extended period of time, as shown in **Fig. 4**, the newly developed polyolefin resin adhesive showed little degradation in mechanical properties and demonstrated that it is free from the issue of molecular weight decrease caused by hydrolysis.

Furthermore, in a hot water immersion test at 85°C, its adhesive strength changed little from the initial value, proving that the newly developed adhesive has substantially excellent moist heat and hot water resistance in comparison with conventional polyester adhesive, as shown in **Fig. 5**.

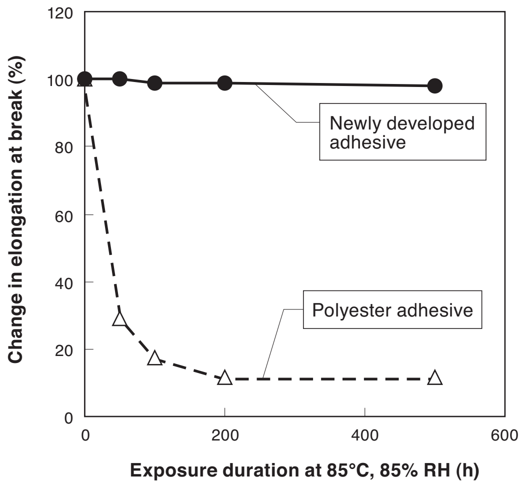

Fig. 4. Variation over time in mechanical properties of adhesive

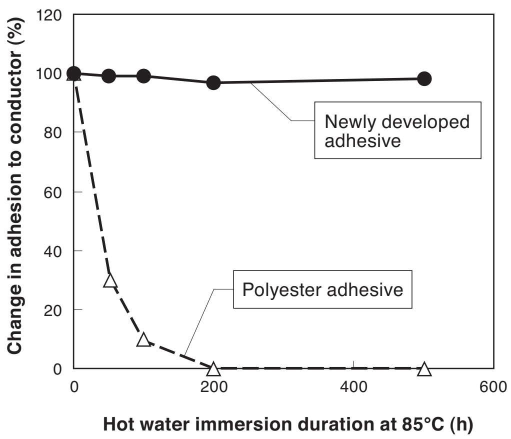

Fig. 5. Variation over time in adhesive strength

2-3 Development of new anchor coating

As stated early, in insulating tapes used to construct flexible flat cables, an anchor coat is provided at the interface between the base film and adhesive for increased adhesion reliability.

The anchor coating is made from a polyurethane resin. Polyurethane resins are classified into polyester, polyether and polycarbonate resins, according to the type of polyol used as the basic ingredient, as shown in **Fig. 6**. In general, polyester, polyether and polycarbonate resins are considered excellent in adhesion, low-temperature resistance and hydrolysis resistance, respectively. The resins are selected according to specific characteristic requirements.

Using these polyurethane resins as anchor coatings, we created insulating tapes by laminating the PET base film and the aforementioned newly developed polyolefin adhesive, and tested the characteristics of the resulting prototype flexible flat cables.

HO−R−OH (Polyol) + OCN−R'−NCO (Isocyanate)

→ •••−O−R−O−CO−NH−R'−NH−CO−O−•••

Polyurethane

Polyol type	Feature
Polyester	Adhesion
Polyether	Low-temperature resistance
Polycarbonate	Hydrolysis resistance

Fig. 6. Types and structures of anchor coatings

The test specimens showed gradual decreases in adhesive strength in the hot water test, as shown in **Fig. 7**. Even test specimens using polycarbonate polyurethane, which is regarded as excellent in hydrolysis resistance, exhibited noticeable decreases in adhesive strength after 28 days of immersion.

We attributed this to hydrolysis of the polyurethane anchor coating. We therefore analyzed the relationships between hydrolysis resistance and the molecular structures of the monomers comprising the polyurethane resin, then tested the adhesive strength and other performance characteristics of the polyurethane resin as anchor coating. By repeating this process, we successfully developed a new anchor coating that is excellent in hydrolysis resistance.

The newly developed anchor coating showed only minor reduction in adhesive strength after 35 days of immersion in hot water at 85°C, as shown in **Fig. 7**, which was a promising result for achieving the goal for hot water resistance.

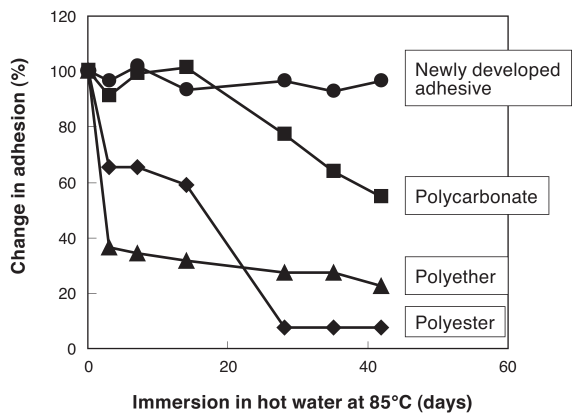

Fig. 7. Hot water resistance comparison of anchor coatings

2-4 Evaluation of cable characteristics

We fabricated insulating tapes by applying the aforementioned anchor coating (3 µm thick) to PET base film (25 µm thick) and laminating a polyolefin adhesive layer (50 µm thick). Prototype flexible flat cables were created by laminating rectangular soft copper conductors (0.035 mm thick × 0.3 mm wide). **Table 3** shows characteristic test results.

The prototype passed heat and low-temperature resistance tests, 45° angle and vertical flame resistance tests and a hot water resistance test, as shown in **Table 3**.

Regarding moist heat resistance, the prototype exhibited satisfactory insulation as it passed the dielectric strength test under conditions of 60°C and 95% RH for 1000 h. However, under conditions of 85°C and 85% RH for 1000 h, the PET base film underwent hydrolysis, partially generating cracks in the PET film from bending, resulting in test failure due to decreased electrical insulation.

To provide a solution, for the base film we studied use of polyphenylene sulfide (PPS) film, which is excellent in moist heat resistance though it costs more than the PET film, for applications requiring cable moist heat resistance under conditions of 85°C and 85% RH for 1000 h.

Table 3. Prototype cable test results (PET base)

Item	Environmental test condition	Test	Test result	Limit
			PET base	
Heat resistance	125°C 3000 h	Insulation resistance in water	10^9 Ω·m min.	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	No breakdown	No breakdown
Moist heat resistance	60°C 95%RH 1000 h	Insulation resistance in water	10^9 Ω·m min.	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	No breakdown	No breakdown
Moist heat resistance	85°C 85%RH 1000 h	Insulation resistance in water	NG	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	NG	No breakdown
Hot water resistance	Hot water at 85°C for 35 days	Insulation resistance in water	10^9 Ω·m min.	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	No breakdown	No breakdown
Low-temperature resistance	−40°C for 8 days Bending	Insulation breaking off	No breaking off	No breaking off
Thermal shock resistance	−40°C −125°C 1000 cycles	Insulation resistance in water	10^9 Ω·m min.	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	No breakdown	No breakdown
Flame resistance		45° angle flame test	Flame duration within 70 seconds	Flame duration within 70 seconds
		Vertical flame test	Flame duration within 60 seconds	Flame duration within 60 seconds

We prepared insulating films by applying the anchor coating (3 µm thick) to PPS base film (25 µm thick) and overlaying polyolefin adhesive film (50 µm thick). A prototype flexible flat cable was fabricated via lamination of rectangular soft copper conductors (0.035 mm thick × 0.3 mm wide) between the insulating films. The resulting prototype satisfied all specification requirements shown in **Table 4**, including the conditions of 85°C and 85% RH for 1000 h.

Table 4. Prototype cable test results (PPS base)

Item	Environmental test condition	Test	Test result	Limit
			PPS base	
Heat resistance	125°C 3000 h	Insulation resistance in water	10^9 Ω·m min.	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	No breakdown	No breakdown
Moist heat resistance	60°C 95%RH 1000 h	Insulation resistance in water	10^9 Ω·m min.	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	No breakdown	No breakdown
Moist heat resistance	85°C 85%RH 1000 h	Insulation resistance in water	10^9 Ω·m min.	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	No breakdown	No breakdown
Hot water resistance	Hot water at 85°C for 35 days	Insulation resistance in water	10^9 Ω·m min.	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	No breakdown	No breakdown
Low-temperature resistance	−40°C for 8 days Bending	Insulation breaking off	No breaking off	No breaking off
Thermal shock resistance	−40°C −125°C 1000 cycles	Insulation resistance in water	10^9 Ω·m min.	10^9 Ω·m min.
		Dielectric strength test 2 kV 1 min	No breakdown	No breakdown
Flame resistance		45° angle flame test	Flame duration within 70 seconds	Flame duration within 70 seconds
		Vertical flame test	Flame duration within 60 seconds	Flame duration within 60 seconds

3. Conclusion

High-performance flexible flat cables have been developed that meet various customer requirements, such as moist heat resistance and the flame resistance specified in UL standards for electronic equipment, as well as heat, low-temperature, flame and hot water resistance specified in ISO and JASO standards for automotive insulated wires.

The newly developed cables are already used for in-vehicle applications. We expect that they will be more widely used in the future.

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Contributors (The lead author is indicated by an asterisk (*).)

Y. FUKUDA*

• Assistant Manager, Electronics & Materials R&D Laboratories
He has been engaged in the devolopment of electric insulation film and adhesive material.

H. HAYAMI
• Senior Specialist
Manager, Electronics & Materials R&D Laboratories

K. NAKAMURA
• Sumitomo Electric Flat Components, Inc.

T. OKU
• Sumitomo Electric Flat Components, Inc.

T. MATSUDA
• Assistant Manager, Sumitomo Electric Flat Components, Inc.