Flexible Printed Circuit with High-Temperature Long-Term Reliability

Takayuki YONEZAWA*, Shingo KAIMORI, Masaaki YAMAUCHI, Masaya KAKIMOTO, Yuki ISHII and Yoshifumi UCHITA

The flexible printed circuit (FPC) is commonly used in electronic equipment including portable devices. Due to its thinness and lightness, the FPC is being increasingly used for LEDs and in-vehicle applications. For these uses, however, the major problem is long-term reliability at high temperatures: whereas the FPC needs to be heat resistant up to 100°C for use in electronic devices, LEDs and in-vehicle applications require a higher resistance up to 150°C. Sumitomo Electric Industries, Ltd. has developed an adhesive with high heat resistance and thus created an FPC that withstands up to with 150°C.

Keywords: FPC, adhesive, polyimide, long-term reliability at high temperatures

1. Introduction

Flexible printed circuits (FPCs) are widely used in electronic devices as an indispensable component offering the benefits of being compact, thin, and highly pliable. Since our first research into FPCs in 1965, Sumitomo Electric Industries, Ltd. has produced a number of products[1] that meet a wide range of needs in the electronics industry by developing Sumitomo Electric's exclusive technologies based on the company's abundant creativity and production skills related with copper wiring. Table 1 shows the main features of an FPC. Compared with a rigid circuit board, an FPC is thinner and more flexible. Further, compared with a flat cable, FPCs are more suitable for high-density wiring. It is for these reasons that they are now being increasingly used in LED lighting and for in-vehicle connections. However, this wider usage has generated a new demand: standard electronics devices are generally used in environments of less than 100°C, while LEDs and vehicle usage may exceed this temperature. Therefore, an FPC now needs to be able to function at temperatures of 100°C or greater—ideally, with a heat resistance as high as 150°C. In order to respond to such needs, we have developed an FPC that can endure continuous use with high reliability at 150°C. This paper discusses the details of this product.[2]

Table 1. Features of FPC

Circuit type	FPC	Flat Cable	Rigid Circuit Board
Thickness	< 0.1 mm	< 0.1 mm	< 0.2 mm
Pattern Density (L/S)	0.050 mm /0.050 mm	0.300 mm /0.200 mm	0.050 mm /0.050 mm
Curcuit Design Flexibility	Branching Available	One-to-One wiring	Branching Available
Circuit Hierarchical Structure	Single Layer Multilayer	Single Layer	Single Layer Multilayer
Limitation in length	< 550 mm	None	< 550 mm
Pliability	good	good	poor

2. Aims of Development

2-1 Basic FPC structures

There are two types of FPC structures: one is a single-sided FPC, in which a conductor is mounted on one side; the other is double-sided, in which conductors are mounted over two layers (Fig. 1). In these structures, conductive wirings (copper circuits with copper plating) are electrically insulated by sandwiching them between two polyimide films, which are then bonded with adhesive using thermocompression. Among these materials, the adhesive reveals the lowest thermal reliability; therefore, improving the adhesive's thermal reliability is the key to improving the thermal reliability of the entire FPC.

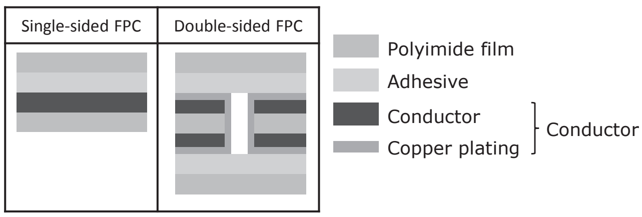

Fig. 1. Cross-Section View of Basic FPC Structure

2-2 Aims of development

Car electronics have advanced significantly in recent years and the performance of related devices has improved. The engine compartment of a car, where temperatures can be extremely high, is now equipped with a variety of electronic components, including sensors, electronic control units (ECUs),*[1] and actuators. This has raised the need for a high-density FPC that is thin and light. Figure 2 shows the in-vehicle target areas in which Sumitomo Electric's FPC can be utilized.

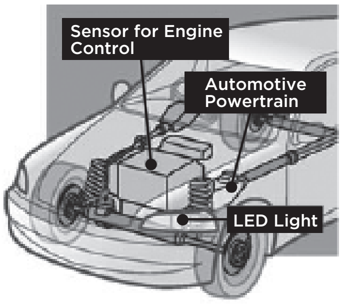

Fig. 2. In-Vehicle Target Areas for FPCs

However, if a conventional FPC is used at a temperature of 150°C, the adhesive, which has the lowest thermal reliability, deteriorates first, causing the polyimide film to peel off from the conductor. Our aim was thus to develop an adhesive with high thermal reliability.

3. Development of FPC Adhesive with Long-Term High Thermal Reliability

3-1 Development targets

ISO 6722 specifies cables intended for use in road vehicles and the heat resistance specifications are classified in a range from A to H. Resistance to 150°C is equivalent to Class D. The procedure for a long-term heat-aging test is specified as follows: after placing the test samples in the test environment at a designated temperature for 3,000 hours, perform the winding test and make a visual examination for any breakage in the insulation. However, there is no industrial standard equivalent to ISO 6722 for an FPC, and therefore, we set our target as "retaining the peel strength required for an FPC (3.4 N/cm or more as defined in the JPCA Standards*[2]) after placing in an environment at 150°C for 3,000 hours." Other target values were also set for product reliability in a high temperature and high humidity vehicle environment (temperature-humidity reliability),and oil-resistance reliability against automatic transmission fluid (ATF) oil.*[3] In addition to these, the adhesive must also provide good peel strength, heat resistance against soldering, and filling capability to ensure insulation between the wirings. Table 2 lists the target values for development.

Table 2. Development Targets

Items	Target Values
(I). Long-term thermal reliability	
Peel strength after 3,000 hours at 150°C	≥ 3.4 N/cm
Peel strength after 3,000 hours at 85°C/85% rh	≥ 3.4 N/cm
Peel strength after 3,000 hours of immersion in ATF oil* at 150°C	≥ 3.4 N/cm
(II). FPC general characteristic requirements	
Peel strength	≥ 8 N/cm
Heat resistance against soldering	≥ 280°C
Filling performance within gaps between wires	Non-void

* Toyota genuine ATF oil Type WS

3-2 Material design

The conventional adhesive for FPCs mainly uses general purpose thermoplastic resin that offers high peel strength, such as acrylic resin or polyamide as a base with thermosetting epoxy resin mixed in. This results in the crosslinking of the molecules, thereby achieving heat resistance against soldering. However, the maximum continuous service temperature of this general purpose thermoplastic resin is as low as 100°C—the very reason why the long-term thermal reliability of conventional FPCs is not good. We therefore started to search for a better resin to use as an adhesive. Polyimide, the main component of an FPC, features heat resistance against soldering and long-term thermal reliability. However, polyimide cannot achieve sufficient insulation because it does not fill the gap between wirings as it is not softened by the heat from thermo-compression. For this FPC, we assessed the possibility of using a copolymer resin as an adhesive. The resin was created by copolymerizing*[4] polyimide resin, which itself offers long-term thermal reliability, with a special thermoplastic resin that shows good capability of filling between wirings and long-term thermal reliability. This was achieved utilizing the technology acquired by Sumitomo Electric over the years to synthesize thermo-resistant resin. In this copolymer resin, the polyimide skeleton and that of the thermoplastic resin are bonded

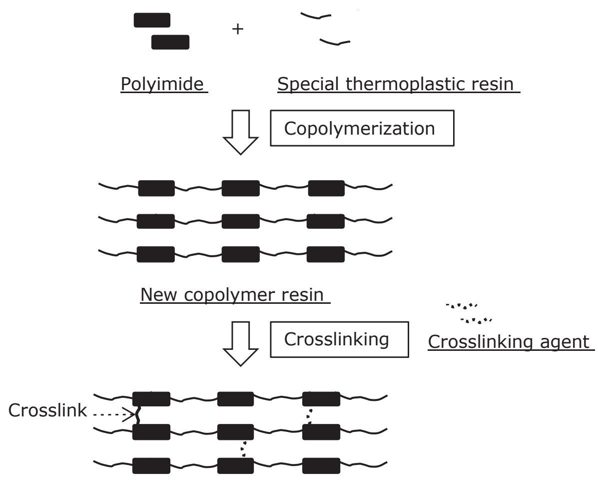

Fig. 3. Representational Model of Sumitomo Electric's New Adhesive

repeatedly. Thus, when thermocompression is applied, the thermoplastic resin is softened, thereby filling the gaps between wirings, while the polyimide satisfies the required long-term thermal reliability. Further, cross-linking copolymer resins should ensure heat resistance against soldering. Based on this material design policy, we synthesized a new copolymer resin in which the copolymerization ratio of the polyimide and thermoplastic resin is optimized. By crosslinking the two copolymer resins using an agent, the resin successfully delivers the long-term thermal reliability, the gap-filling capability, and the heat-resistance against soldering that are generally required of an FPC. Figure 3 shows this newly developed adhesive, which is exclusive to Sumitomo Electric.

4. FPC Performance Assessment

In order to assess the product's reliability, we created a sample FPC utilizing the newly developed adhesive and a surface-treated circuit board, along with a control sample for comparison purposes using Sumitomo Electric's conventional adhesive and a surface-treated circuit board. The respective sample FPCs are hereafter referred to as the New FPC and the Conventional FPC. These FPCs were then assessed in terms of their thermal reliability at 150°C, temperature-humidity reliability at 85°C and 85% rh, and oil-resistance reliability in ATF oil at 150°C. The samples were then removed from the test environment and the peel strength assessment test was conducted on them at room temperature using the 180-degree SIGN peel method (JIS K6854) and a tensile tester, the Autograph AG-IS, manufactured by Shimadzu Corporation.

(1) Thermal Reliability at 150°C

The New and Conventional FPCs were placed in a test chamber at a constant temperature of 150°C for 3,000 hours, and their peel strength was then measured. The results showed that the New FPC possesses a higher thermal reliability compared with the Conventional FPC, fulfilling the requirement specified by the JPCA Standards (≥ 3.4 N/cm) after 3,000 hours at 150°C (Fig. 4).

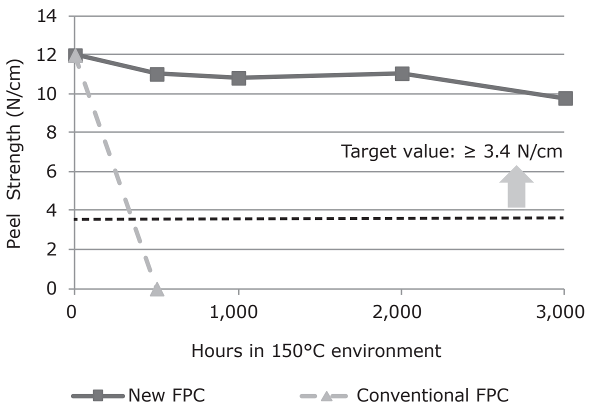

Fig. 4. Thermal Reliability at 150°C of New and Conventional FPCs

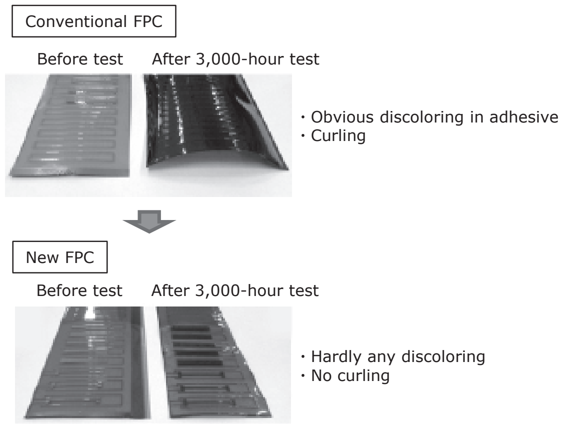

Fig. 5. Comparison between Conventional FPC and New FPC

(2) Temperature-Humidity Reliability at 85°C and 85% rh

Figure 6 shows changes in the peel strength of the New and Conventional FPCs over the 3,000 hours in a chamber at 85°C and 85% rh. The New FPC did not show any significant sign of deterioration in peel strength after the 3,000 hours.

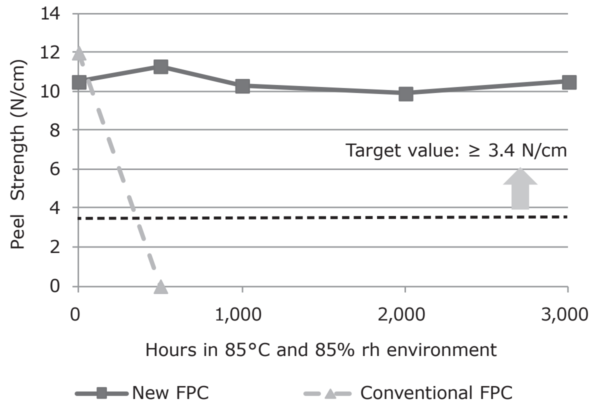

Fig. 6. Temperature-Humidity Reliability at 85°C and 85% rh of New and Conventional FPCs

(3) Oil-Resistance Reliability in 150°C ATF Oil

Figure 7 shows changes in the peel strength of the New and Conventional FPCs over the 3,000 hours immersed in ATF oil at 150°C. Peel strength deteriorates due to the swelling of the adhesive caused by penetration of the oil; however, the New FPC maintained a performance level that fulfills the requirements specified by the JPCA Standards (≥ 3.4 N/cm) after the 3,000 test hours, while the peel strength of the Conventional

FPC reaches zero after 500 hours (Fig. 7).

Table 3 summarizes the assessment results of the New FPC. The New FPC was created by utilizing the newly developed adhesive and components mounted by soldering, and its performance was assessed using the tests described above. The New FPC's long-term thermal reliability satisfied all the target values, and the heat resistance against soldering also marked as high as 360°C. Neither was any void observed in the adhesive-filled gaps between wirings. The insulation was confirmed to be sound by measuring the insulation resistance when applying 50 V power to the New FPC's circuit with a minimum 50 μm pitch in an environment at 85°C and 85% rh.

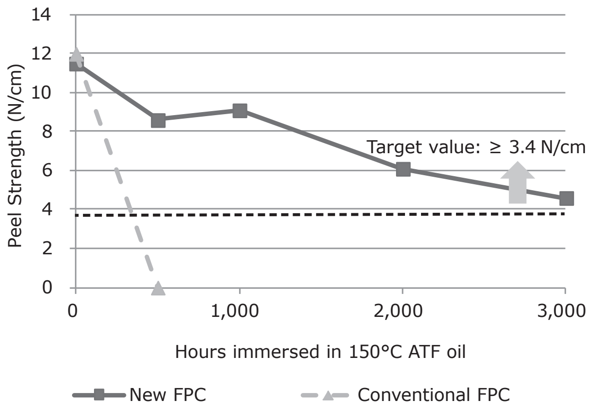

Fig. 7. Oil-Resistance Reliability in 150°C ATF Oil of New and Conventional FPCs

Table 3. New FPC Assessment Results

Items	Target Values	New FPC
(I). Long-term thermal reliability		
Peel strength after 3,000 hours at 150°C	≥ 3.4 N/cm	9 N/cm
Peel strength after 3,000 hours at 85°C/85% rh	≥ 3.4 N/cm	10 N/cm
Peel strength after 3,000 hours of immersion in ATF oil at 150°C	≥ 3.4 N/cm	5 N/cm
(II). FPC general characteristic requirements		
Peel strength	≥ 8 N/cm	≥ 10 N/cm
Heat resistance against soldering	≥ 280°C	360°C
Filling performance within gaps between wires	Non-void	None
Insulation resistance	≥ 1.0×10^{8} Ω	4.8×10^{11} Ω

5. Conclusion

We developed an FPC that can be used in LED lighting and for in-vehicle applications utilizing a newly developed polyimide adhesive that remains functional in a high-temperature environment. This new product was confirmed to satisfy the JPCA Standards required for in-vehicle cables after 3,000 hours at a temperature of 150°C. The product is expected to find a wide range of applications in vehicles as car electronics further advance.

Technical Terms

*1 ECU: Electronic Control Unit. A component that determines the appropriate injection quantity and timing of fuel and the ignition timing, based on information gathered from various sensors.

*2 JPCA Standards: Standards for printed circuit boards specified by Japan Electronics Packaging and Circuits Association.

*3 ATF Oil: Automatic Transmission Fluid oil. A type of oil used for vehicles equipped with an automatic transmission.

*4 Copolymerization: To synthesize a high polymer compound, a number of low polymer compounds are linked, and these become the components of the final high-polymer compound. This process is known as polymerization. Polymerization that involves two or more monomers is known as copolymerization.

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

T. YONEZAWA*

• Energy and Electronics Materials Laboratory

S. KAIMORI

• Assistant General Manager, Energy and Electronics Materials Laboratory

M. YAMAUCHI

• Group Manager, Energy and Electronics Materials Laboratory

M. KAKIMOTO

• Ph.D.
Assistant General Manager, Sumitomo Electric Printed Circuits, INC.

Y. ISHII

• Sumitomo Electric Printed Circuits, INC.

Y. UCHITA

• Group Manager, Sumitomo Electric Printed Circuits, INC.