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Flexural Fatigue Life Evaluation for Flexible Printed Circuit Boards

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Abstract
We report test results of bending characteristics of flexible printed circuit board, which contributes to the development of higher density and more sophisticated function of mobile devices and electronic equipment. Our report shows that there is a correlation between mechanical structure and the bending characteristics of flexible printed circuit boards, and that ultra thin structure shows excellent performance in bending applications. We also find that elasticity modulus of adhesive plays a key role in the bending characteristic of flexible printed circuit board. We have utilized the finite element method to evaluate the strain for investigation of the bending fatigue mechanism. We will report on the study of a formula with which we can estimate the flexural fatigue life. We also show the analysis result of generated stress when various constructions of flexible printed circuit boards are bent.

Introduction
Flexible printed circuit board (hereinafter referred to FPC) is thin and has excellent flexibility. It is used in personal computer peripherals and mobile equipment that have shown tremendous improvement in functions recently. Flexibility is the most remarkable characteristic of FPC. Therefore, flexural durability is one of the most important functions for FPC.
In this paper, we report the results of our investigation as follows:
a) Relationship between construction and flexibility
b) Concrete measures for improvement of flex life
c) Technique to predict the flexural fatigue life at the design stage.

FPC with High Flexibility
Construction and Bending Characteristics
As shown in Figure 1, FPCs usually has single sided construction (1 layer of conductor).

We investigated the relationship between construction or material and flexibility by using FPC specimens of our original design based on the IPC 240 standard. Figure 2 shows our investigation method of flexibility based on the IPC 240 standard. The evaluation results from this test method are shown in Figures 3, 4, 5 and 6. Figure 3 shows the relationship between total thickness and flexural fatigue life of FPC. Figure 4 shows the relationship between elastic modulus of the adhesive and flexural fatigue life of FPC. Figure 5 shows the relationship between elastic modulus of polyimide film and flexural fatigue life of FPC. And Figure 6 shows the flexural fatigue life of copper foil and flexural fatigue life of FPC. According to above data, the flex property of FPC can be improved either by reducing total thickness of FPC or by using high elastic modulus adhesive.

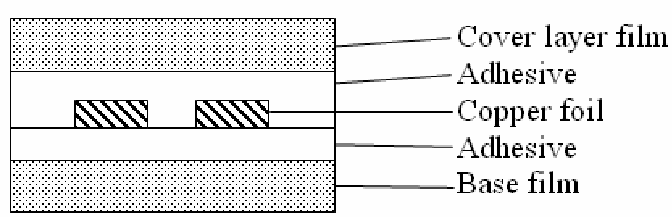

Figure 1 – Cross Section of FPC

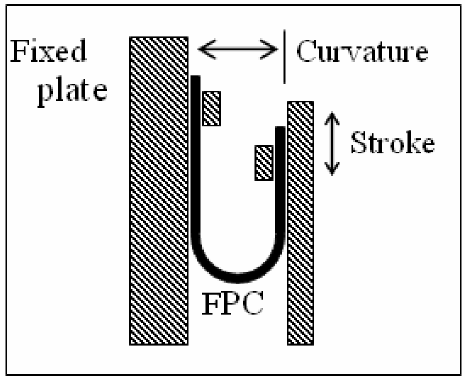

Figure 2 – IPC Flex Tester

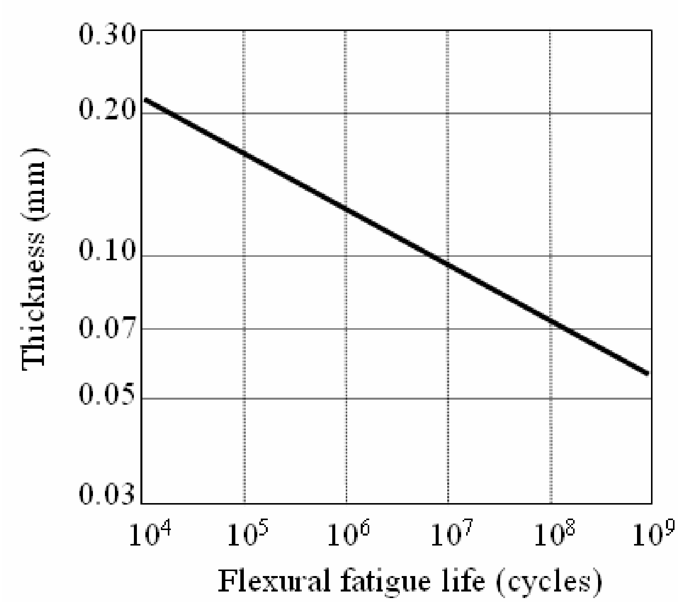

Figure 3 – Relationship between Thickness of FPC and Flexural Fatigue Life

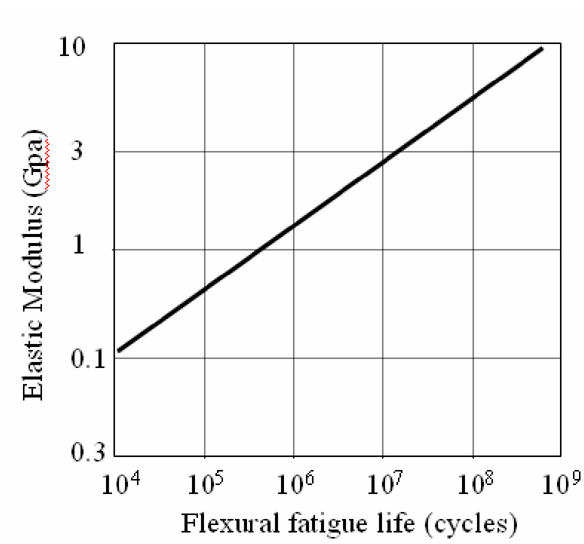

Figure 4 – Relationship between Elastic Modulus of Adhesive and Flexural Fatigue Life

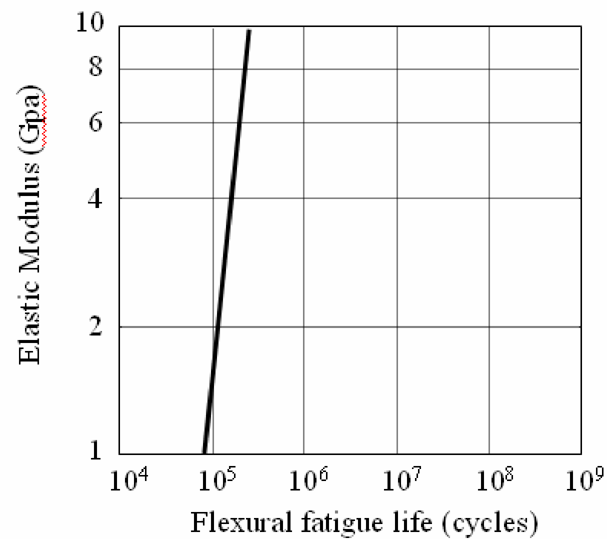

Figure 5 – Relationship between Elastic Modulus of PI Film and Flexural Fatigue Life

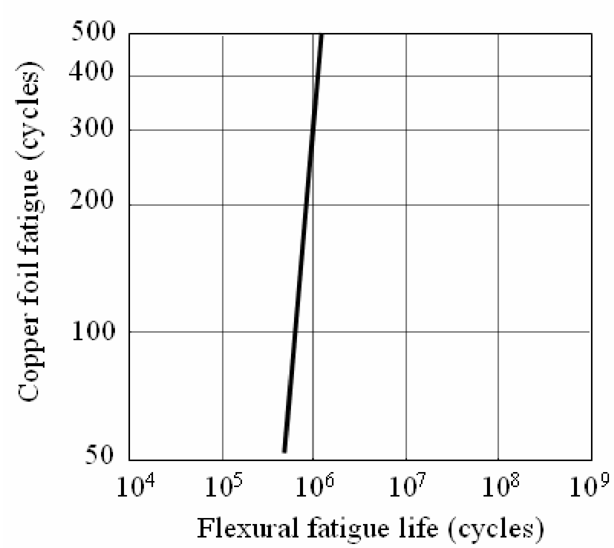

Figure 6 – Relationship between Copper Foil Fatigue and Flexural Fatigue Life

Ultra Thin FPC

We prepared ultra thin FPC with 0.005mm thick base insulation layer, 0.010mm thick conductive layer, and 0.005mm thick cover insulation layer. We have done the ductility test of the ultra thin FPC. The ductility test is a kind of bending test for FPC. Specimen is set between two metal bars called mandrels as shown in Figure 7. The specimen and mandrels were moved vertically together up and down between supporting rollers. Figure 8 shows the ductility test result of ultra thin FPC. This test result proves that the ultra thin FPC is has excellent flexibility.

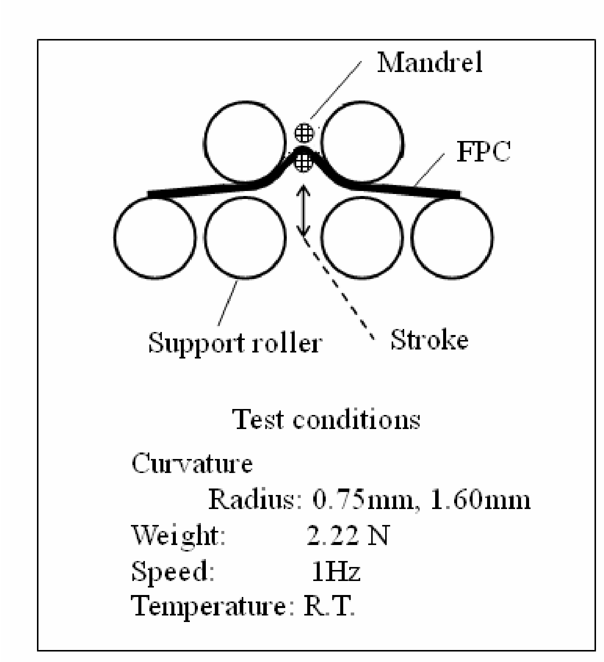

Figure 7 – Ductility Tester

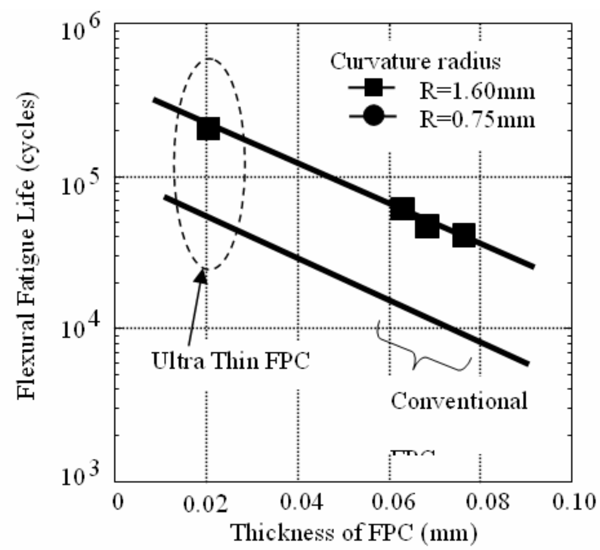

Figure 8 – Relationship between Thickness of FPC and Flex Fatigue Life

FPC for High Temperature

FPC used in HDD or DVD has been requiring higher flexibility under high temperature environment due to the temperature increase during operation. Figure 9 shows the flexibility test result of two types of FPCs, which are made with conventional type adhesive and with high temperature application adhesive. The test method and test conditions were based on the IPC 240 standard under the temperature of 80 degree C. According to Figure 9, the FPC with high temperature application adhesive has better flexibility property in high temperature environment. Figure10 shows correlation between temperature and elastic modulus of both conventional adhesive and high temperature application adhesive. Adhesive with less elastic modulus loss under high temperature enables FPC to have better bending characteristics in a high temperature environment.[1]

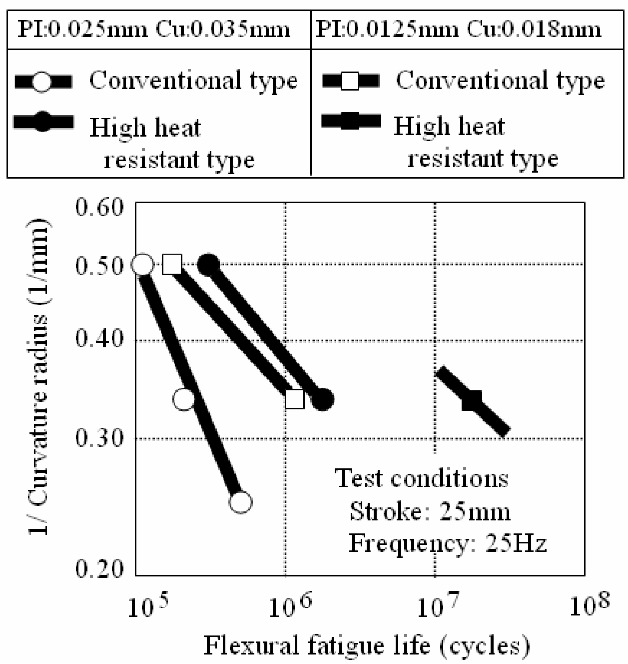

Figure 9 – Relationship between Curvature Radius and FPC Flex Fatigue Life at 80° C

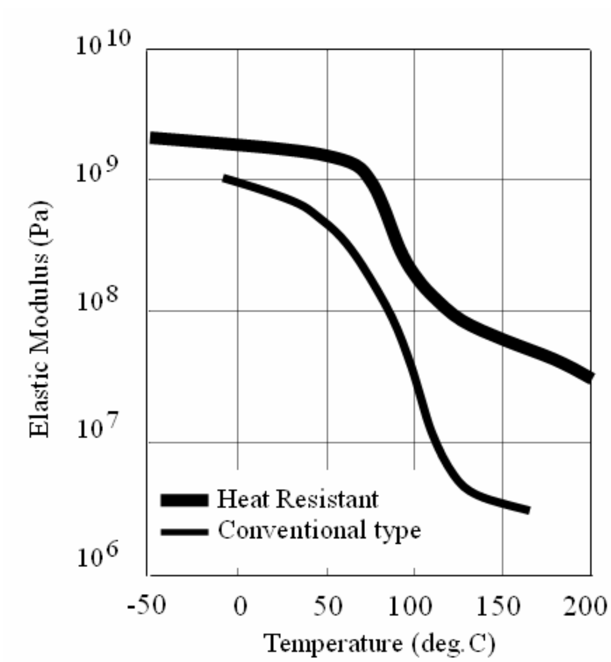

Figure 10 – Relationship between Elastic Modulus of Adhesive and Temperature

Prediction Technique of Flexural Fatigue Life

Flexural fatigue Life of FPC

If we can predict the flexural fatigue life of FPC at the designing stage, we will be able to develop it more effectively[2]. The flexural fatigue of FPC is a phenomenon that strain inflicted on dynamic area repeatedly causes breakage of conductive circuits. Therefore, it will be possible to predict the flexural fatigue life if we can monitor the degree of the strain[3].

Bending Analysis Using the Finite Element Method

We analyzed the strain on the bending area of copper foil using elastic-plastic analysis based on the finite element method. The construction of FPC is identical to Figure 1. Table 1 shows the characteristics of the materials of FPC. Three types of adhesive with different elastic modulus were used. We did 2-dimensional elastic-plastic analysis using hypothesis that copper foil and adhesive are elastic-plastic materials while polyimide film is an elastic material. The boundary condition in accordance with the IPC 240 standard is shown in Figure 11. As the result of the finite element method, actual bending radius during dynamic action tends to be smaller than the radius under static conditions. Figure 12 shows the result. In order to verify above result, we took photos of bending FPC with a high-speed camera. This confirmed that the shape of the FPC is quite similar to the result from the finite element method.

Table 1 – Thickness and Physical Property of FPC Materials (80° C)

	Thickness (nm)	Bastic Modulus	Poisson's Ratio
Polyimide	0.025	4000	0.35
Copper Foil	0.035	47000	0.34
Adhesive 1	0.020	2800	0.40
Adhesive 2	0.020	1700	0.40
Adhesive 3	0.020	1200	0.40

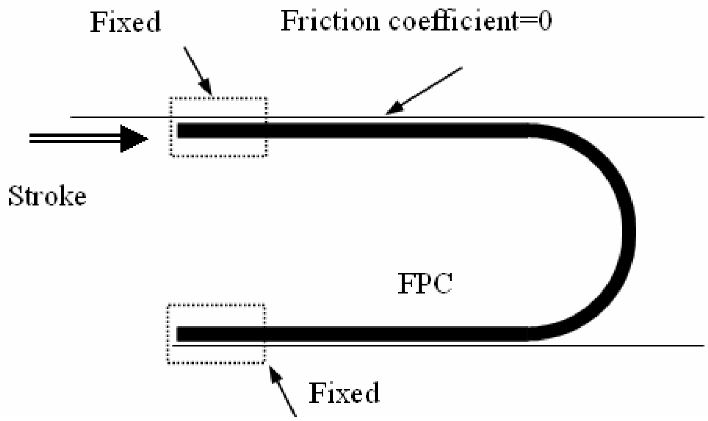

Figure 11 – Boundary Condition

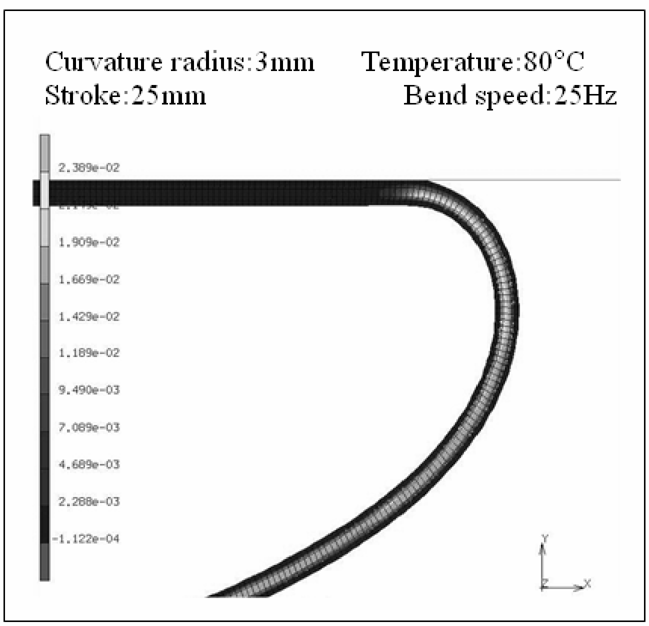

Figure 12 – Change in Shape of FPC (Analysis using FEM)

Predictive Formula of the Flexural Fatigue Life

We analyzed the strain on copper foil under various conditions with the finite element method by using specimens of which materials and constructions are shown in Table 1. Figure 13 shows the relationship between the result of the analysis with the finite element method and actual test result of flexural fatigue life based on IPC 240 standard. From Figure 13, the life prediction curve can be shown as a single master curve that is not dependent on environmental temperature, the type of adhesive, or curvature radius. As a result, we were able to obtain the following predictive formula of flexural fatigue life.

$$Nf=1.66x10^{-31} \text{ x } E^{-31.7} \qquad \text{Eq. (1)}$$

Here, Nf is fatigue life, and E is strain on bending area of copper foil
If we can measure the strain on the copper, approximate flexural fatigue life can be predicted based on the Formula (1).

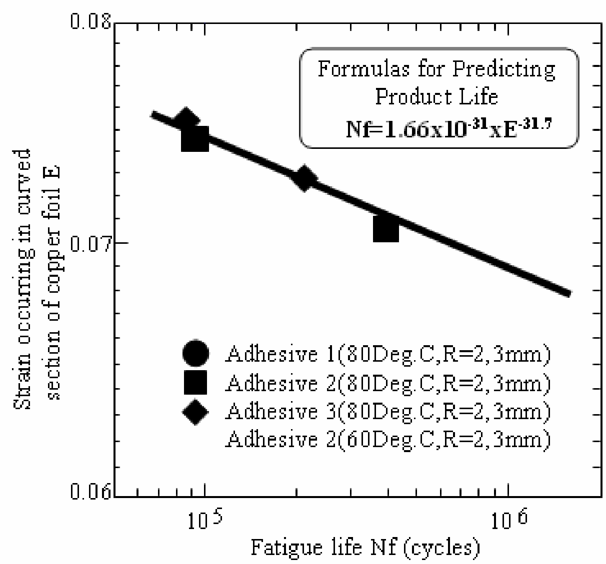

Figure 13 – Relationship between Strain on Curved Section of Copper Foil and Fatigue Life

Construction of FPC and Stress

It is important to study the relationship between FPC construction and generated stress, because the less stress that occurs when FPC is bent, the longer the flexural fatigue life becomes. The stress analysis for bent FPC was implemented on the double-sided FPC shown in Figure 14. The constructions of the specimens are shown on Table 2. Table 3 shows the properties of raw materials of FPC used in the analysis. Figure 15 shows the stress analysis result for various constructions.

Here, we normalized all of the data so that the maximum stress generated on the standard construction shown on Figure 14 is 100%. According to Figure 15, the thinner copper foil or polyimide film becomes, the smaller the stress becomes. We also discovered that drastic stress reduction is possible if conductors on top and bottom are aligned in a staggered arrangement.

Table 2 – Analysis condition of FPC Structure

		Copper		Polyimide (mm)	Note
		Thickness（mm	L/S		
1	Standard	0.018	0.050/0.05	0.025	
2	Thickness of Cu	0.012	0.050/0.05	0.025	
3	Thickness of PI	0.018	0.050/0.05	0.0125	
4	Adhesive	0.018	0.050/0.05	0.025	Thickness : 0.010mm
5	Plain Cu for backside	0.018	0.050/0.05	0.025	
6	Staggered	0.018	0.050/0.05	0.025	

Table 3 – Physical Property of Materials

	Young's modulus (Gpa)	Poisson's ratio (-)
Rolled foil	70.0	0.3
Polyimid	4.0	0.3
Adhesive	1.7	0.3

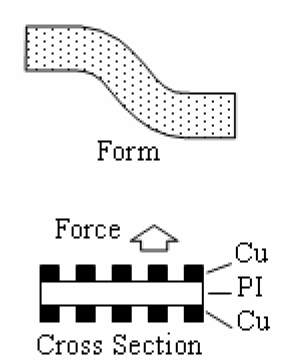

Figure 14 – Analysis Model

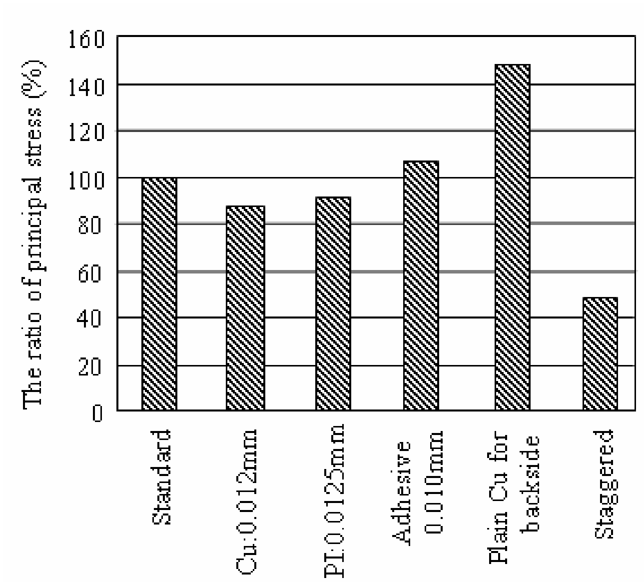

Figure 15 – Relationship between Strain on Curved Section of Copper Foil and FPC Structure

Conclusion

We showed that total thickness of FPC and elastic modulus of adhesive have a great influence on the flexibility characteristics, which is one of the most important functions of FPC. We presented the ultra thin FPC and the high temperature application FPC as concrete examples of improved flexibility characteristics. We also reported the predictive formula of flexural fatigue life at design stage of FPC by using the finite element method. In addition, we reported the analysis result of generated stress when the various constructions of FPC were bent.

Reference

1) C. Miyaake, Flexural Fatigue Life Evaluation for Flexible Printed Circuit Boards at High Temperature, Nitto Technical Report, Vol.37, No.2, 38, Nov, (1999)
2) K. Douta, C. Miyaake, K. Miyake, Development of Flexible Printed Circuit Boards using Fatigue Life Prediction, Nitto Technical Report, Vol.39, No.1, 68, May, (2001)
3) H. Suzuki, A Study on the Lifetime of Flexible Printed Circuits under Bending Based on the Conventional Works of Fatigue, JSME (A), vol.57, No.534, 449, (1991)