Development of Mini-MT Ferrule Using Short-Cycle Injection Molding

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ABSTRACT Injection molding is attracting attention as a short-cycle molding method for Mini-MT ferrules that comprise optical connectors. The authors investigated the material, molds, molding conditions, and polishing technologies for injection molding Mini-MT ferrules, and succeeded in developing the ferrules having the same level of precision as those by conventional transfer molding. The 4-fiber Mini-MT connector comprised of the developed 4-fiber Mini-MT ferrules gave such excellent optical characteristics as 0.107 dB on average for insertion loss and 45 dB or better on average for return loss, in addition to stabilized insertion loss changes at reliability tests. Furthermore, the insertion and return losses of the 2-fiber Mini-MPO connector comprised of the 2-fiber Mini-MT ferrules were 0.18 dB on average and 45 dB or better on average respectively, and the connector showed small insertion loss changes.

Thus, optical characteristics of injection molded Mini-MT ferrules proved to be equivalent to those of transfer molded ferrules. Since it is possible to make the cycle time of injection molding shorter than that of transfer molding thereby enabling low-cost production, the use of injection molded ferrules is expected to broadly spread in future.

1. INTRODUCTION

As the optical network business based on the information highway plan develops in recent years, optical fibers are gradually being employed as backbone lines in on-premises cabling. While conventional metal cables are used in floor-level cabling making only a limited transmission capacity available, optical fiber cables are capable of high-speed data communication. [1)~3)] In the future, FTTD (fiber to the desk) implementation based on optical fiber cabling will extend to desktop personal computers thus creating a large demand for optical connector components. On the other hand, to adapt to the needs of high-capacity data transmission, optical fiber transmission cables are becoming multi-cored and densely packed, so that a large demand for multi-fiber optical connectors which permit collective connection of these cables is rapidly developing.

At present, multi-fiber optical connectors in actual use include the MT (mechanically transferable) connector. [4), 5)] In order to satisfy the required optical characteristics, the MT connector necessitates high precision manufacturing technologies that assure a positional precision of the submicrons order; and the technologies have already been established in which MT ferrules are molded by transfer molding using thermosetting polymer compound.

Recently however, as mentioned before, a large demand for multi-fiber optical connectors is rapidly developing calling for lower costs. This accordingly requires a short-cycle molding technology that brings about not only high precision but also higher productivity than conventional technologies. There has also been a need for connection in 2- and 4-fiber units requiring optical connectors having a more compact, denser structure than the MPO

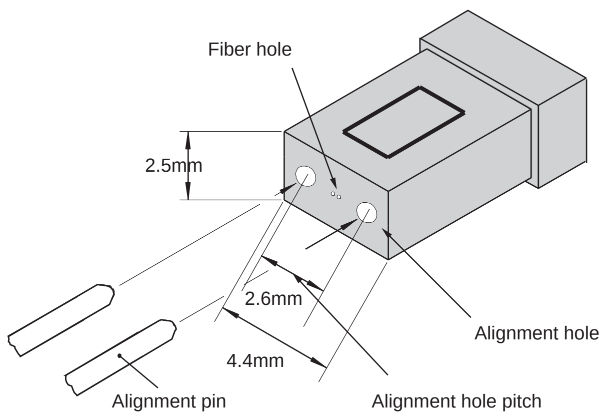

Figure 1 Structure of Mini-MT ferrule

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(multifiber push-on) connector. This led to a design having no more than four fibers and the development of the Mini-MT connector, based on the MT connector. [6)]

This report describes the development of injection molded Mini-MT ferrules that provide, at lower molding costs, optical characteristics which are equivalent to those obtained with transfer molded MT ferrules.

2. BASIC STRUCTURE OF MINI-MT FERRULE

As shown in Figure 1, the Mini-MT ferrule is provided with two alignment-pin holes together with fiber holes in which fibers are to be inserted. In order to have such excellent optical characteristics as are obtained with conventional transfer molded ferrules, it is essential for an injection molded ferrule to have a positional accuracy of the submicrons order in the dimension between the alignment-pin holes as well as in the relative position between the alignment-pin holes and the fiber holes.

Figure 2 shows the structure of an assembled Mini-MT connector, in which the ferrules with a fiber ribbon each are optically connected using two alignment pins and a clamp spring.

3. INJECTION MOLDING TECHNOLOGY

3.1 Development Concept

Optical characteristics of MT ferrules are controlled by the diameter of alignment-pin holes, the pitch of alignment-pin holes, fiber hole diameter, and the offset of fiber holes. The challenging tasks of managing these parameters have been solved by the development of new thermosetting polymers having low molding shrinkage in addition to the upgrading of transfer molding technologies, resulting in the production of MT ferrules with a high dimensional precision of the submicrons order.

Thus, the MT connector is drawing attention in the field of data communication. In order to cope with a large demand anticipated, the MT connector is required to have mass productivity and low cost. Therefore, in an effort to realize low cost production of ferrules that provide optical characteristics equivalent to those of transfer molded ferrules, new Mini-MT ferrules have been developed based on the injection molding technology.

3.2 Material Technology

We have been investigating the injection molding technology as well as the transfer molding technology. The investigation has shown that it is important to select a thermoplastic polymer of low molding shrinkage for injection molding, and that the stabilization of molding shrinkage depends, needless to say, on molding conditions and molds in addition to such important factors as polymer species and filler shape. We have carefully studied the material parameters of base polymers together with the shape, size, distribution, and quantity of filler, finally succeeding in developing a compound suitable for injection molding.

The developed compound is excellent in molding stability and mechanical strength. The strength of alignment-pin holes on molded ferrules was measured to prove that the ferrule had the same level of mechanical strength as that of conventional ferrules.

3.3 Molding Technology

Precision transferring of the mold is known to be very important in molding technology. In injection molding, the process is such that the dried compound is supplied into the hopper of the injection machine, heated to melt in the cylinder, and the melted compound is injected into the mold. Properly pressurized until gate solidification, the product is cooled in the mold, and then it is taken out.

It is essential, accordingly, to establish the optimum conditions to carry out the process of injection, pressurizing, and cooling of the melted compound without giving strain onto the molding pins for the fiber holes. Only under such conditions, stabilized products with superior positional precision can be obtained.

3.4 Fiber Ribbon Attachment and Polishing

A fiber-optic ribbon is inserted into the ferrule with its coating removed at the end, and is fixed using epoxy adhesive.

The easiness of subsequent flat polishing of the endface depends substantially on the property of the polymer used. After various studies, a set of polishing conditions was successfully found to meet the requirements of the

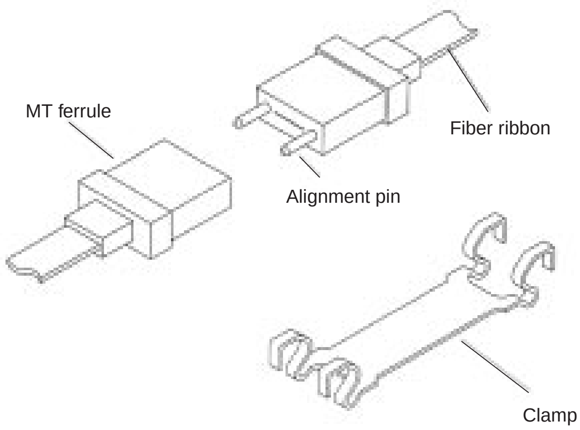

Figure 2 Structure of Mini-MT connector

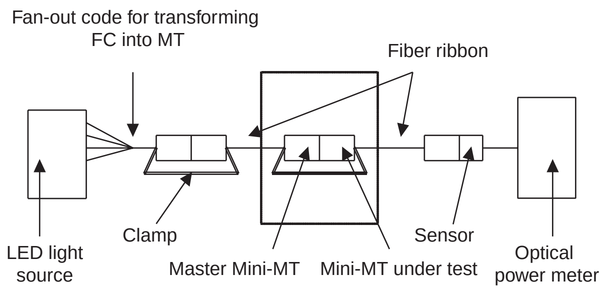

Figure 3 Measuring system configuration

injection molded ferrules, realizing a satisfactory polished end-face of excellent flatness.

4. OPTICAL CHARACTERISTICS

The insertion loss was measured by the versus-master method in which the loss with respect to a standard plug having an extremely small offset in fiber holes was measured. The light source was an LED of 1310-nm wavelength, and index matching material or matching oil was applied to the point of connection. Figure 3 shows the measuring system configuration.

The core fibers are arrayed symmetrically on the centerline of the two alignment-pin holes, so that measurements were made in both the normal and the 180° reversed connections.

4.1 Single-Fiber Mini-MT Ferrule

Figure 4 shows the insertion loss histogram of the single-fiber Mini-MT connectors using the single-fiber Mini-MT ferrule, and Table 1 those of single-, 2-, and 4-fiber connectors. The loss was 0.11 dB on average with a maximum of 0.29 dB for normal connection, and 0.159 dB on average with a maximum of 0.46 dB for reversed connection --satisfactory connection performance. Moreover, since no much difference is seen between the normal and reversed connection losses, it may be concluded that there is no specific tendency in the direction and quantity of the offset of fiber holes, and that the targeted positional precision has been almost realized.

Table 2 shows the return loss of Mini-MT connectors, satisfactory results of 45 dB or better on average.

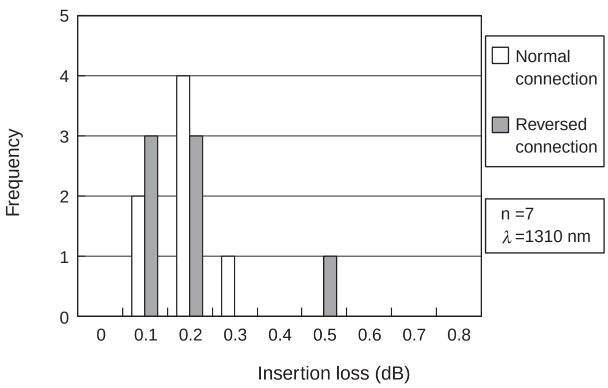

Figure 4 Insertion loss histogram of single-fiber Mini-MT connector

Table 1 Insertion loss of Mini-MT connector

	Average insertion loss (dB)					
	Single-fiber Mini-MT		2-fiber Mini-MT		4-fiber Mini-MT	
Connection	Normal	Reversed	Normal	Reversed	Normal	Reversed
n	7	7	60	60	40	40
Average	0.16	0.159	0.21	0.262	0.107	0.195
Maximum	0.29	0.46	0.43	0.54	0.24	0.44

λ=1310 nm

Table 2 Return loss of Mini-MT connector

	Return loss (dB)		
	Single-fiber Mini-MT	2-fiber Mini-MT	4-fiber Mini-MT
n	10	20	24
Average	45 dB or better	45 dB or better	45 dB or better

λ=1310 nm

4.2 2-Fiber Mini-MT Ferrule

Figure 5 shows the insertion loss histogram of the 2-fiber Mini-MT: 0.21 dB on average with a maximum of 0.43 dB for normal connection, and 0.262 dB on average with a maximum of 0.54 dB for reversed connection --satisfactory connection performance. The fact that the insertion losses are nearly the same for the normal and reversed connections shows that the 2-fiber holes are arranged almost symmetrically with respect to the ferrule center.

4.3 4-Fiber Min-MT Ferrule

Figure 6 shows the insertion loss histogram of the 4-fiber Mini-MT: 0.107 dB on average with a maximum of 0.24 dB for normal connection, and 0.195 dB on average with a maximum of 0.44 dB for reversed connection --satisfactory connection performance. Although the positional deviation of each fiber hole with respect to the alignment pins tends to increase with the number of fibers, the insertion loss is seen to maintain its small values thanks to the selections of material and mold as mentioned before.

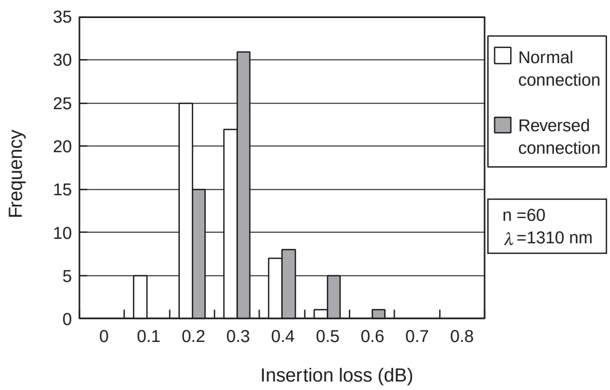

Figure 5 Insertion loss histogram of 2-fiber Mini-MT connector

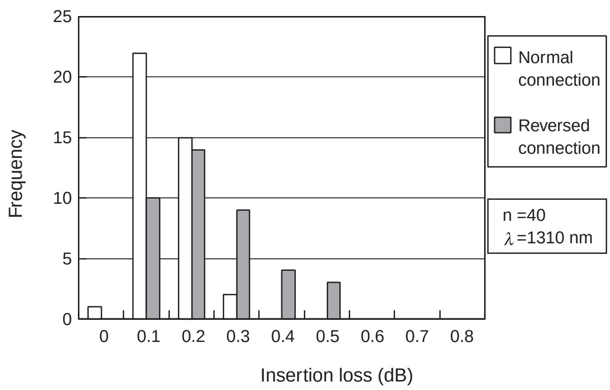

Figure 6 Insertion loss histogram of 4-fiber Mini-MT connector

Table 3 Results of mechanical tests

Test item	Conditions	Insertion loss change (Average)	
		Injection	Transfer
Connection-disconnection	100 connection-disconnections Loss measurement every 10 repetitions With refractive index matching material	0.20 dB or less	0.20 dB or less
Pull	5.9 N in the optical axis direction	0.20 dB or less	0.20 dB or less
Vibration	Frequency: 10~55 Hz Amplitude: 1.5 mm Direction: 3 directions Duration: 2 hr/direction	0.20 dB or less	0.20 dB or less
Shock	Intensity: 100 G x 6 ms Direction: 3 directions Repetition: 3 times/direction	0.20 dB or less	0.20 dB or less
Bend	Load: 6.8 N/fiber at fiber-end 1 m away Direction & Repetition: ±90 deg. x 100 times bending Loss measurement every 10 repetitions	0.20 dB or less	0.20 dB or less
Drop	Height: 1.5 m Fiber length: 2 m Repetition: 3 times on concrete surface	0.20 dB or less	0.20 dB or less

λ=1310 nm
In accordance with JIS C 5981

Thus, it has been confirmed that the fiber holes are located almost as exactly as designed.

5. RELIABILITY TESTS

Results of typical reliability tests on selected 4-fiber Mini-MT connectors are given below.

The reliability tests consist of mechanical characteristics evaluation under mechanical strains and temperature characteristics evaluation done from an environmental standpoint. The measurement results with conventional transfer molded connectors are shown for comparison.

5.1 Evaluation of Mechanical Characteristics

Table 3 shows the test item, test conditions, and results of mechanical characteristics evaluation. The test conditions are in accordance with JIS C 5981.

Connection-disconnection tests were performed reconnecting two connectors 100 times and the insertion loss change was measured every 10 repetitions. The result was 0.20 dB or less, as good as transfer molded connectors.

Pull tests were done by measuring the insertion loss changes before and after pulling the connector at 5.9 N in the axial direction. The result was satisfactory, with 0.20 dB or less.

Furthermore, vibration, shock, bend, and drop tests were performed; the insertion loss change was 0.20 dB or less in every test, equivalent to the performance of transfer molded MT connectors obtained in similar tests. This confirmed that there was no practical problem in terms of mechanical characteristics.

Table 4 Results of temperature tests

Item	Conditions	Insertion loss change (Average)	
		Injection	Transfer
Heat-cycle	-40~60°C, 10 cycles, 6 hr/cycle	0.20 dB or less	0.20 dB or less
High-temperature	80°C x 96 hr	0.20 dB or less	0.20 dB or less
Low-temperature	-40°C x 96 hr	0.20 dB or less	0.20 dB or less
Humid	60°C x 95% RH x 96 hr	0.20 dB or less	0.20 dB or less

λ=1310 nm
In accordance with JIS C 5981

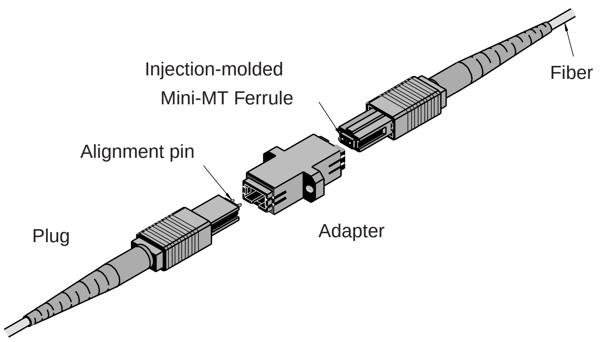

Figure 7 Structure of Mini-MPO connector

5.2 Temperature Characteristics Evaluation

Table 4 gives representative of the test item, conditions, and results of temperature characteristics evaluation.

Heat-cycle tests were carried out by measuring the insertion loss change under the conditions of -40~60°C, 10 cycles, and 6 hr/cycle. The result was satisfactory, with 0.2 dB or less. Furthermore, high-temperature, low-temperature, and humid tests were performed; the insertion loss change was 0.20 dB or less in every test, equivalent to the performance of transfer molded connectors.

6. MAKING MINI-MT FERRULE INTO MPO [7), 8)]

6.1 Structure

Mini-MPO connector, a push-on/pull-off type connector as shown in Figure 7, has been developed using the Mini-MT ferrule.

6.2 Optical Characteristics

As representative of Mini-MPO connectors, the 2-fiber connector using injection molded 2-fiber Mini-MT ferrule and 2-fiber ribbon has been developed. The end-face of the ferrule was polished to achieve flat PC (physical contact) and the connector was evaluated without refractive index matching material.

Figures 8 and 9 show insertion loss and return loss respectively. While the insertion loss was 0.18 dB on average with a maximum of 0.36 dB --low enough values--, the return loss was 46.2 dB with a minimum of 40 dB --high enough values--.

6.3 Mechanical and Temperature Characteristics

Table 5 gives representative of the test item, conditions, and results of mechanical and temperature characteristics evaluation. The test conditions are in accordance with JIS C 5982.

Mechanical characteristics were evaluated for connection-disconnection, straight pull, side bend, and side pull.

In connection-disconnection tests, a total of 500 reconnections were performed, and the insertion loss was measured every 50 repetitions. The change in insertion loss, within 0.2 dB, was satisfactory and no particular damage to the connectors causing insertion loss increase was observed.

The test conditions for the straight pull, side bend, and side pull tests are shown in Figures 10 to 12. The insertion loss change due to every test was 0.20 dB or lower.

Heat-cycle tests were performed, to evaluate the temperature characteristics, under the conditions of -25~70°C, 10 cycles, and 2.5 hr/cycle. The change in insertion loss due to the test was 0.20 dB or less --a satisfactory value. Table 5 shows the results.

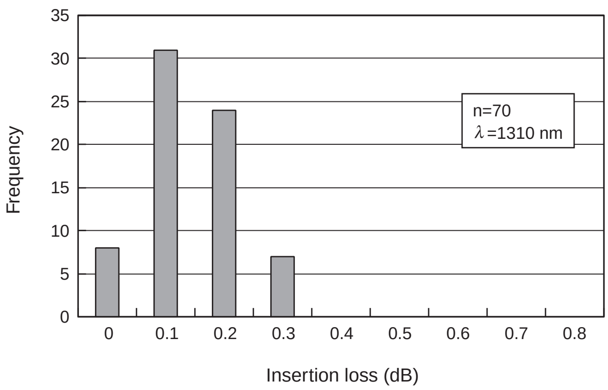

Figure 8 Insertion loss histogram of 2-fiber Mini-MPO connector

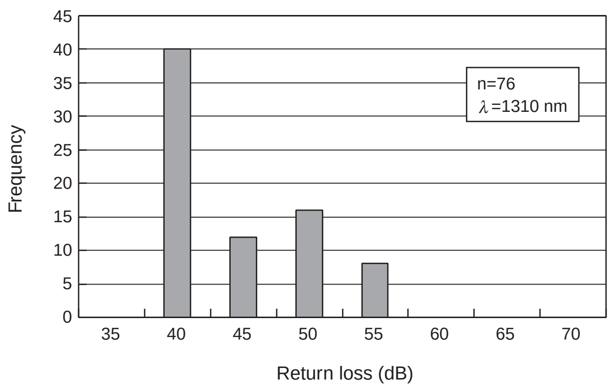

Figure 9 Return loss histogram of 2-fiber Mini-MPO connector

Table 5 Results of mechanical and temperature tests on 2-fiber Mini-MPO connector

Item	Conditions	Insertion loss change (Average)	Return loss (Average)
Connection-disconnection	500 connection-disconnections Loss measurement every 50 repetitions Without refractive index matching material	0.20 dB or less	———
Pull	68.6 N x 1 min	0.20 dB or less	———
Bend	4.9 N x 100 times	0.20 dB or less	———
Side pull	20 N	0.20 dB or less	35 dB or better
Heat cycle	-25~70°C, 10 cycles, 2.5 hr/cycle	0.20 dB or less	———

λ=1310 nm
In accordance with JIS C 5981
BELLCORE specification was referred to in side pull test

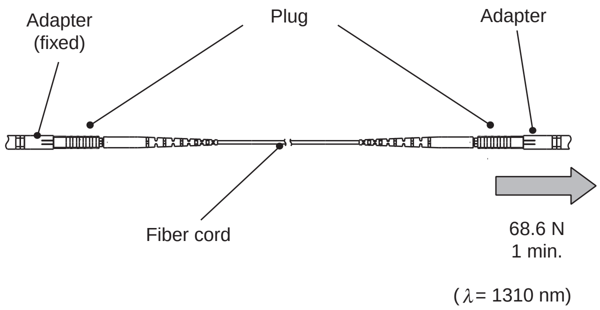

Figure 10 Straight pull test

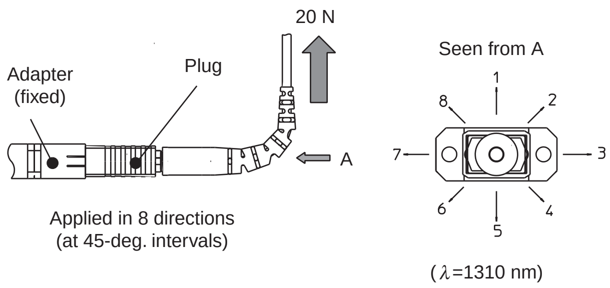

Figure 12 Side pull test

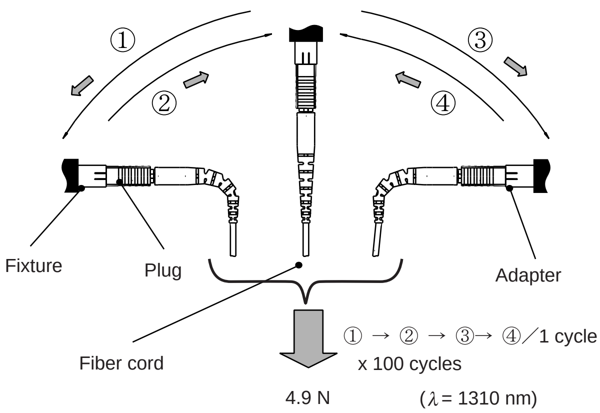

Figure 11 Side bend test

7. IN CONCLUSION

We have developed Mini-MT ferrules and Mini-MPO connectors comprised of the ferrules using injection-molding technology. The developed products gave good performance, which are practically satisfactory, in terms of initial optical and mechanical characteristics as well as long-term reliability.

To summarize their performance, the 4-fiber Mini-MT ferrule, representing the single-, 2-, and 4-fiber Mini-MT ferrules, gave an average insertion loss of 0.107 dB and an average return loss of 45 dB or better; while the 2-fiber Mini-MPO connector, comprised of the Mini-MT ferrule with PC contact and without refractive index matching material, gave an average insertion loss of 0.18 dB and an average return loss of 46.2 dB.

Since injection molded ferrules have shorter cycle time than transfer molded ones, it is possible to bring the cost lower than that of conventional transfer molded ferrules.

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