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TECHNICAL REPORT

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Fibre optic interconnecting devices and passive components – Summarising results of round robin on connector end face scratch recognition and verification by automated microscopes

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FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – SUMMARISING RESULTS OF ROUND ROBIN ON CONNECTOR END FACE SCRATCH RECOGNITION AND VERIFICATION BY AUTOMATED MICROSCOPES

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The text of this Technical Report is based on the following documents:

Draft	Report on voting
86B/4492/DTR	86B/4521/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

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- withdrawn,
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INTRODUCTION

It is known that contamination and scratches on connector end face can result in degradation of optical performance as described in IEC TR 62627-05. It is important to inspect and clean, when necessary, each connector before mating with another connector to ensure they are fit for function. The visual inspection methods and criteria for fibre optic connectors and fibre-stub transceivers are defined in IEC 61300-3-35. Three different methods can be used for visual inspection: direct view optical microscopy (method A), video microscopy (method B) and automated analysis microscopy (method C). All methods are susceptible to system variability: methods A and B are operator dependent; method C is operator independent but relies on software analysis for measurement results. The uncertainty inherent to imaging equipment, processing methods, and detection software can lead to measurement variability among different brands and even the same types of microscopy. For all methods, the fibre microscopes can be certified for use in either low- and high-resolution applications with a purpose-built certification artefact.

There is industry concern about the veracity of the results of the visual inspection of the same part using different automated inspection equipment and software for method C. The IEC SC 86B task force group on scratch recognition was organized to investigate automated inspection system variability and provide recommendations to improve repeatability and reproducibility of the inspection. The task force group specifically limited its investigation to inspection using method C.

The task force group consisted of the following members (in alphabetical order): Arden, CommScope, Corning, Data Pixel, Exfo, Fibre QA, Fluke Corporation, Sumix, University College of London, and decided to perform this investigation by means of a round robin. The round robin involved inspection systems from multiple vendors in a blind study to determine the baseline performance of the systems with regard to automated scratch detection relative to IEC criteria of pre-selected samples.

This report summarizes the results (data collection and analysis) of end face scratch recognition and verification round robin performed by the following task force contributors (5 fibre inspection system manufactures). The following sequence in which the contributors are listed does not represent the order in which the data is presented in the results section. One contributor provided results from four unique inspection systems, each having their own participant ID (eight ID’s in total):

- Data-Pixel;
- Exfo;
- FiberQA;
- Fluke Corporation;
- Sumix.

FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – SUMMARISING RESULTS OF ROUND ROBIN ON CONNECTOR END FACE SCRATCH RECOGNITION AND VERIFICATION BY AUTOMATED MICROSCOPES

1 Scope

This document summarises the results of a round robin on connector end face scratch recognition and verification by automated microscopes. The prime objectives of the study were:

- determine the amount of variability (repeatability and reproducibility) when different state-of-the-art inspection systems are assessed against IEC 61300-3-35:2015;
- evaluate any system-to-system variation in the quantity of reported scratches;
- provide recommendations to improve the repeatability and reproducibility of fibre optic inspection systems.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

4 Round robin procedure

The round robin workflow consisted of the following steps.

a) Specimen preparation (see Clause 5): Multimode and single-mode single-fibre and multi-fibre test specimens were produced. An image of each end face was captured by high resolution microscope, attenuation and return loss were measured for each fibre, and end-face geometry was determined to verify that the specimens met the IEC interface requirements.

b) Circulation initiation: Measurement procedure and results template (see Annex A) were developed and approved by the group. The order of participants for specimen circulation was agreed.

c) Measurements: Specimens were circulated among round robin participants. Every participant performed measurements and collected image data according to the agreed procedure.

d) Analysis of results: The results were gathered from all participants. Data analysis was performed, and the synthesis report was composed.

5 Specimen preparation

5.1 General

The round-robin test specimens were fabricated to consider various interface configurations and conditions. Specimens were arranged into both cylindrical ferrule single fibre (1,25 mm zirconia material) and rectangular ferrule multi-fibre types (12-fibre MT with polyphenylene sulphide [PPS] material). Both multimode (50 µm core diameter) and single-mode specimens were produced.

5.2 Multimode specimens

The multimode specimens were further organised into categories that had pristine fibre end-face surface quality, and ones with low-level, light scratches (produced with a 1 µm diamond film) which still meet functional performance criteria. Furthermore, specimens were created with 1 to 3 heavy scratches (produced with a 5 µm diamond suspension), as well as a control without detectable heavy scratches. A summary describing all of the multimode variants is provided in Table 1. A total of twelve multimode single-fibre specimens and twelve multi-fibre specimens (with three specimens per group) were produced. Images for each of the specimens are given in Figure 1 for the single-fibre and Figure 2 for the multi-fibre groups. All images were taken with an end face inspection system utilizing blue-light illumination, an objective having an NA of 0,40 and a magnification of 400 x (see Figure 1 to Figure 4).

Table 1 – Multimode test specimen categorisation

Group identification	Ferrule type	Ferrule material	Light scratches	Heavy scratches
A MM	1,25 mm	Zirconia	No	No
B MM	1,25 mm	Zirconia	No	Yes
C MM	1,25 mm	Zirconia	Yes	No
D MM	1,25 mm	Zirconia	Yes	Yes
E MM	MT (PPS)	PPS	No	No
F MM	MT (PPS)	PPS	No	Yes
G MM	MT (PPS)	PPS	Yes	No
H MM	MT (PPS)	PPS	Yes	Yes

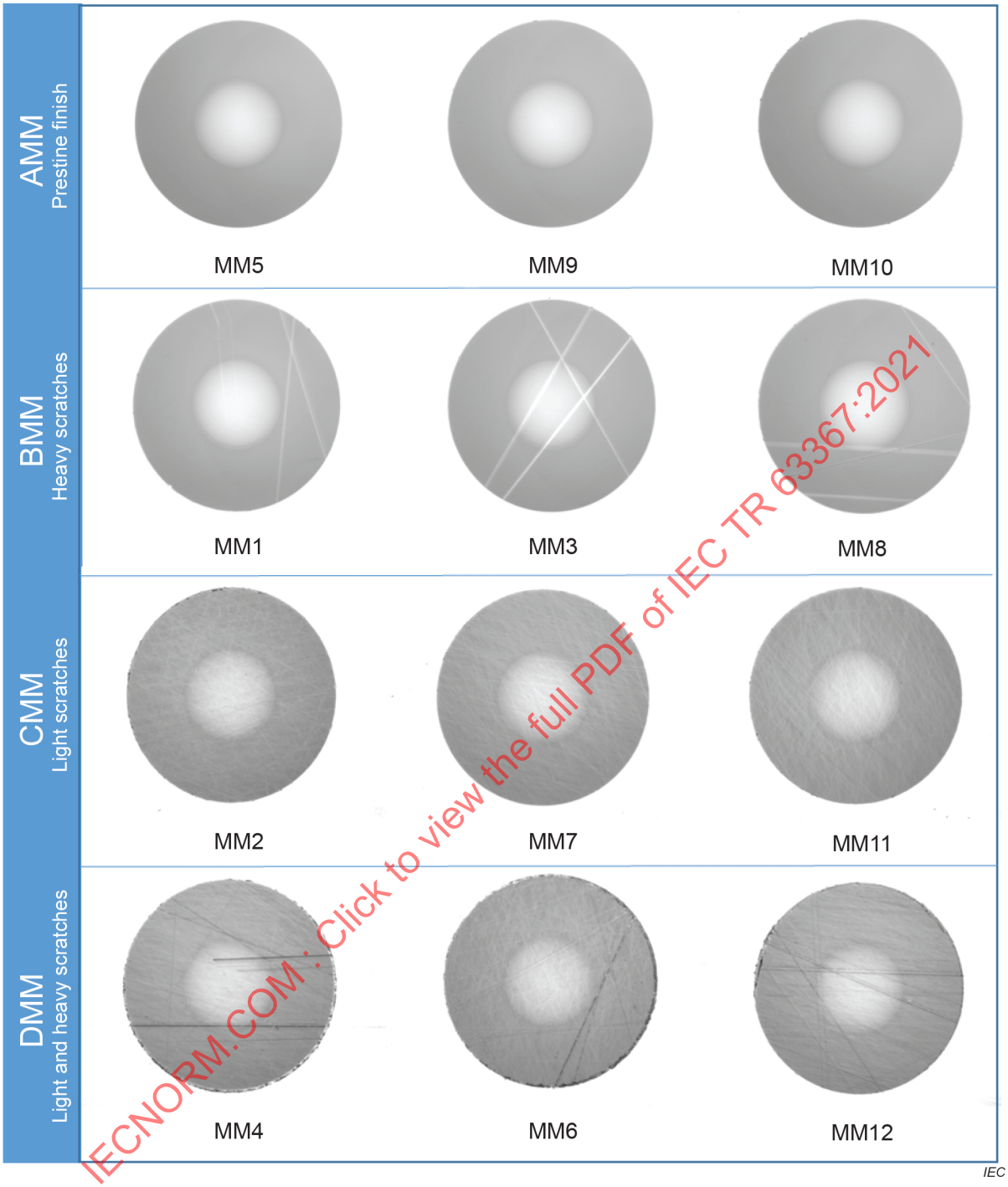


Figure 1 – Multimode single-fibre test specimen grouping

Following visual inspection, the optical performance of each specimen was qualified at 850 nm wavelength and the end-face geometry was determined. The attenuation and return loss were measured per IEC 61300-3-4, insertion method (B), and IEC 61300-3-6, method 1: OCWR, respectively. The results for the single-fibre specimens is reported in Annex B (Table B.1 and Figure B.1 to Figure B.2). End face geometry of the single-fibre specimens was estimated using IEC 61300-3-47 and summarized in Annex B (Table B.2).

The multi-fibre specimens had specific fibres of each ferrule identified for the study. However, attenuation, return loss, and geometry measurements were made across all fibres of the interconnection. A key to identify the fibre specimen inspected during the round robin is provided in Annex B (Figure B.3). Attenuation and return loss values are given in Annex B (Table B.3 to Table B.4 and Figure B.4 to Figure B.5), with the round robin fibre inspection

interfaces highlighted. The end-face geometry of the multi-fibre interfaces was determined using IEC 61300-3-30. The relevant geometric parameters, fibre heights, and core dip results are summarised in Annex B (Table B.5 to Table B.7).

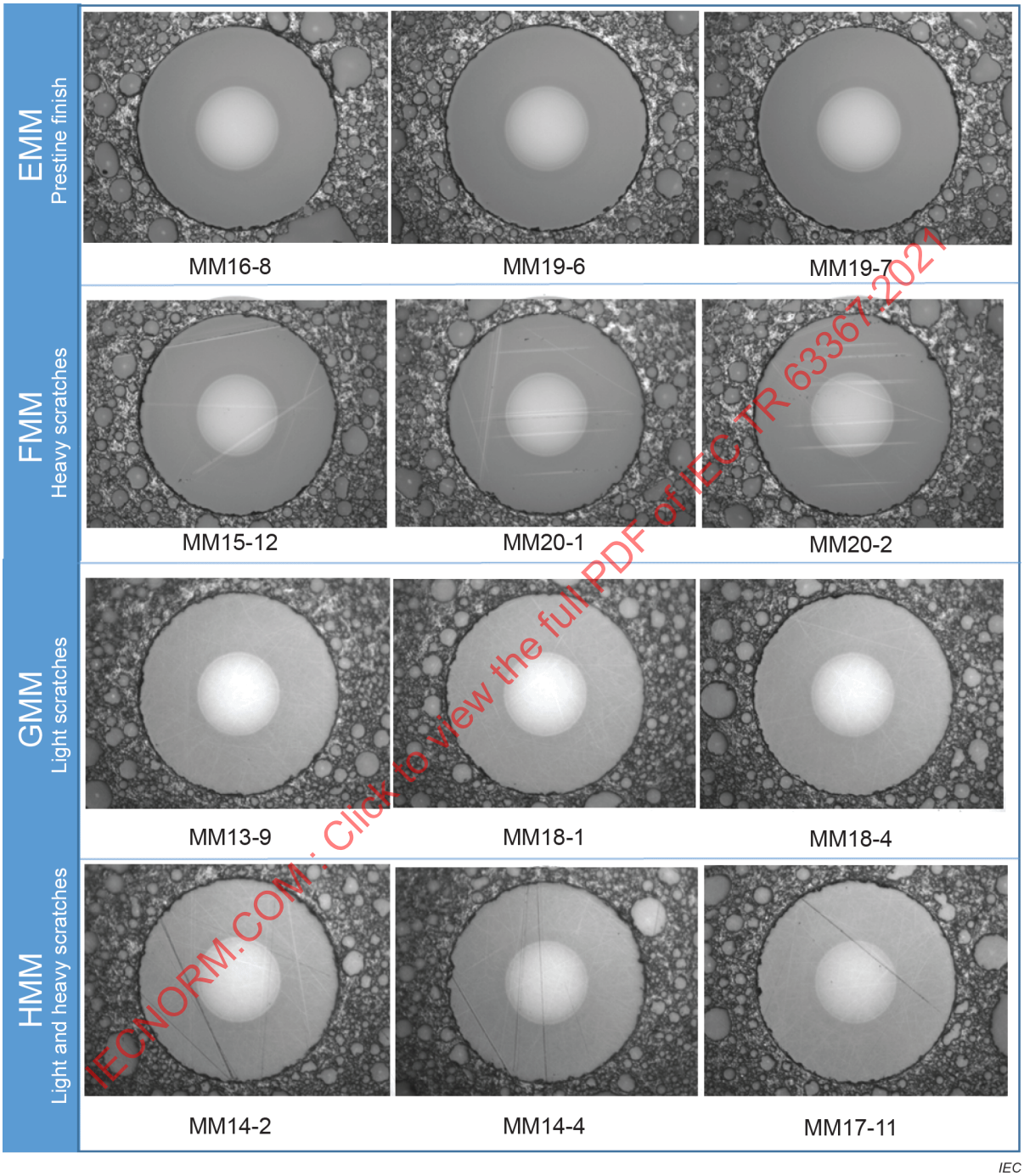


Figure 2 – Multimode multi-fibre test specimen grouping

5.3 Single-mode specimens

The single-mode end faces were binned into categories, which either had 1 to 3 scratches that pass through the fibre core or pass through zone A (without intersecting the core). These scratches were approximately 1 µm width. In addition, a single-mode specimen group without any observable scratches was produced. A summary describing all of the single-mode variants is provided in Table 2. A total of nine single-mode, single-fibre specimens were produced and nine multi-fibre interfaces (with three specimens per group). Images for each of the specimens are given in Figure 3 for single-fibre and Figure 4 for the multi-fibre groups.

Table 2 – Single-mode test specimen categorisation

Group identification	Ferrule type	Ferrule material	Core scratches	Zone A scratches
A SM	1,25 mm	Zirconia	No	No
B SM	1,25 mm	Zirconia	No	Yes
C SM	1,25 mm	Zirconia	Yes	Yes
D SM	MT	PPS	No	No
E SM	MT	PPS	No	Yes
F SM	MT	PPS	Yes	Yes

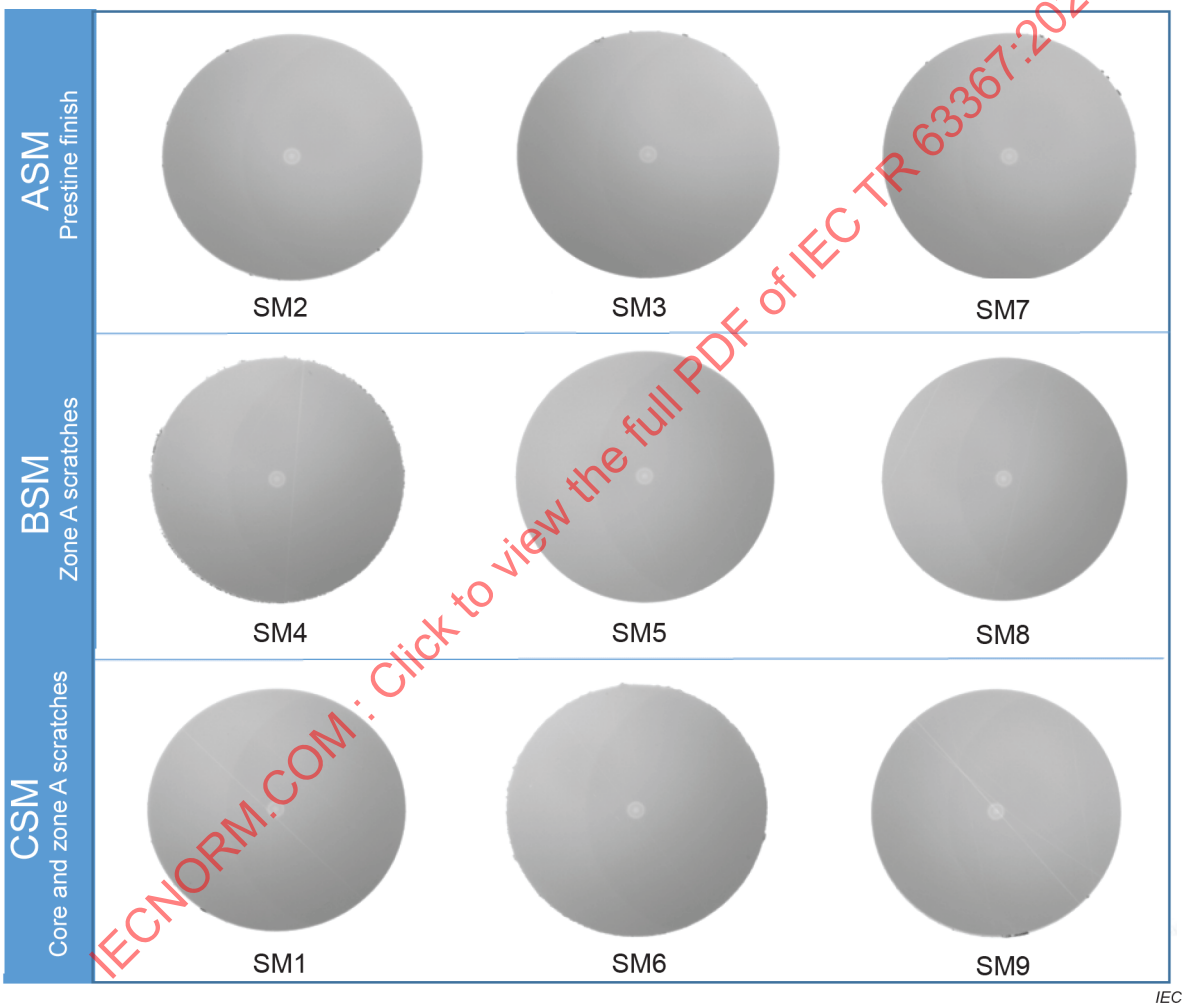


Figure 3 – Single-mode single-fibre test specimen grouping

Following visual inspection, the optical performance of each specimen was qualified at 1 310 nm and 1 550 nm wavelengths, and the end-face geometry was determined. The attenuation and return loss was measured per IEC 61300-3-4, insertion method (B), and IEC 61300-3-6, method 1: OCWR, respectively. The results for the single-fibre specimens are reported in Annex B (Table B.8 and Figure B.6 to Figure B.7). End face geometry of the single-fibre specimens was estimated using IEC 61300-3-47 and summarized in Annex B (Table B.9).

The multi-fibre specimens had specific fibres of each ferrule identified for the study. However, attenuation, return loss, and geometry measurements were made across all fibres of the interconnection. A key to identify the fibre interface inspected during the round robin is provided in Annex B (Figure B.8). Attenuation and return loss values are given in Annex B (Table B.10

to Table B.13 and Figure B.9 to Figure B.10), with the round robin fibre inspection interfaces highlighted. The end-face geometry of the multi-fibre interfaces was determined using IEC 61300-3-30. The relevant geometric parameters, fibre heights, and fibre tip radii are summarised in Annex B (Table B.14 to Table B.16).

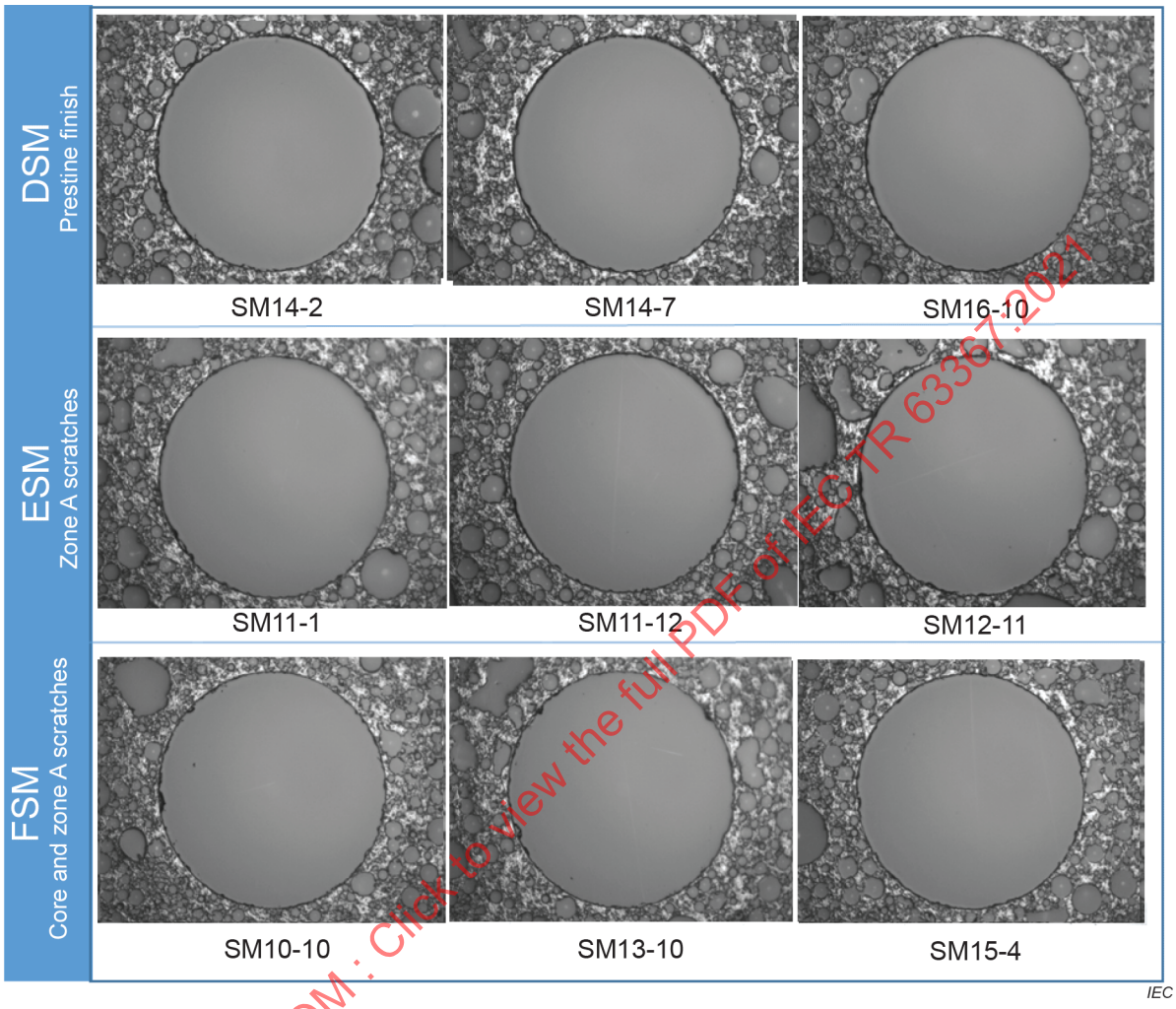


Figure 4 – Single-mode multi-fibre test specimen grouping

6 Results

6.1 Reported data

The participant results were collected and binned into eight different groups, determined by ferrule type, fibre type, and end face zone. Participants only reported the quantity of significant scratches per specimen when assessed to IEC 61300-3-35:2015. No widths were reported. Single-fibre specimens were measured by all participants; however, some inspection systems were not capable of measuring multi-fibre specimens so only five out of eight participants were able to provide results for these specimens. Results for all specimens can be found in Annex C (Figure C.1 to Figure C.4 for multimode and Figure C.5 to Figure C.8 for single-mode).

6.2 Multimode specimens

Multimode finish groups A MM and E MM contain specimens which were to have no significant scratches in either zone A or zone B. One scratch was reported for both of these groups in their entirety. Groups B MM and F MM had the same base, scratch free finish, but also contained a few heavy scratches. The reported results for these two groups varied as much as zero to four significant scratches within a single specimen. Figure 5 to Figure 6 (multi-fibre) contains an end

face image and results from an individual specimen which is representative of the observed differences in group F MM.

Specimens from multimode groups C MM and G MM have finishes with low level, light scratches which are insignificant. Four out of eight participants reported failing scratches on these specimens, with a variation of up to five scratches between those participants.

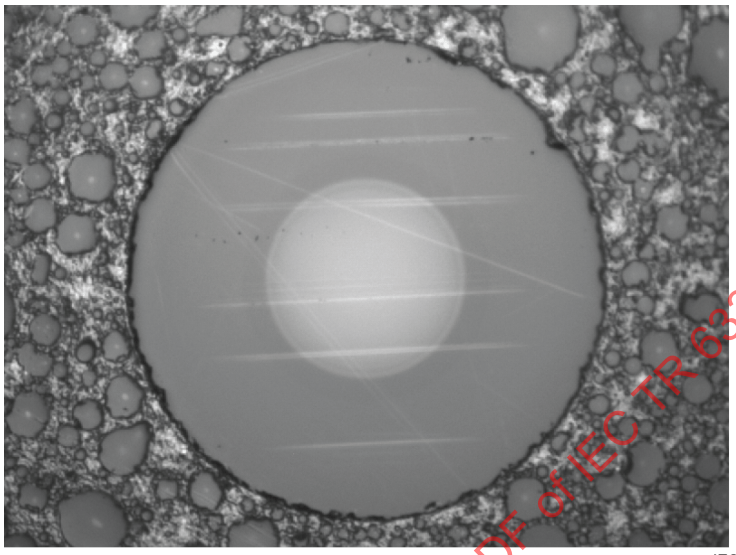


Figure 5 – Image of specimen end face MM20-2

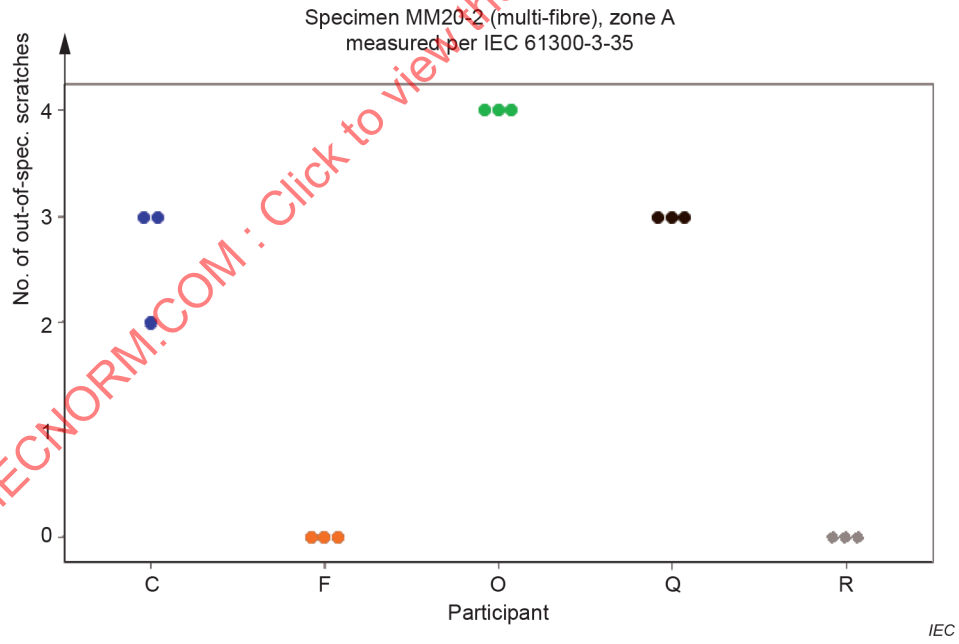


Figure 6 – Number of out-of-specification scratches reported for multimode multi-fibre specimen MM20-2, zone A

Observations of specimen MM20-2

- Two out of five participants do not detect scratches while three others report more than two scratches.
- Repeatability within a participant seems better for multi-fibre sample MM20-2 than for single fibre sample MM12.

Specimens from multimode groups C MM and G MM have finishes with low level, light scratches which are insignificant. Four out of eight participants reported failing scratches on these specimens, with a variation of up to five scratches between those participants. A larger disparity between participants was noted for groups D MM and H MM, which contained specimens with both low level, light scratches and a few heavy scratches. Figure 7 to Figure 8 (single-fibre) and Figure 9 to Figure 10 (multi-fibre) contain results from individual specimens which are representative of the observed differences in groups D MM and H MM.

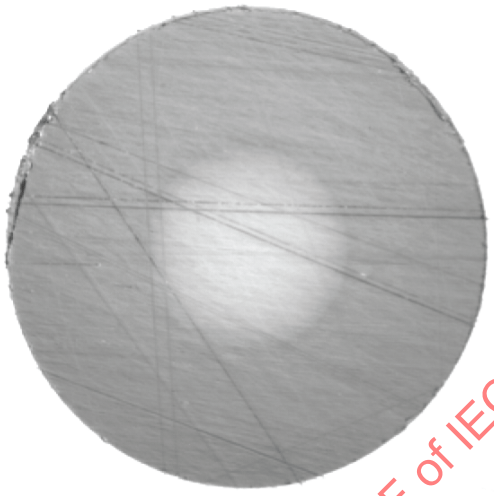


Figure 7 – Image of specimen end face MM12

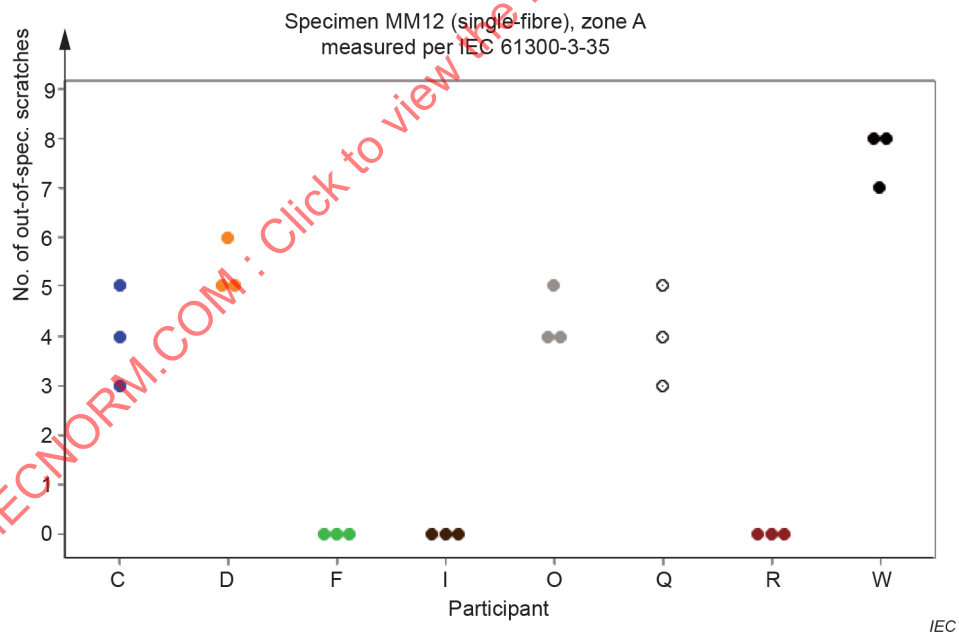


Figure 8 – Number of out-of-specification scratches reported for multimode single-fibre specimen MM12, zone A

Observations of specimen MM12

- Overall results show between zero and eight reported scratches.
- Three out of eight participants do not detect scratches while five others report more than three scratches.
- Repeatability within a participant seems worse for single fibre sample MM12 than for multi-fibre sample MM20-2.

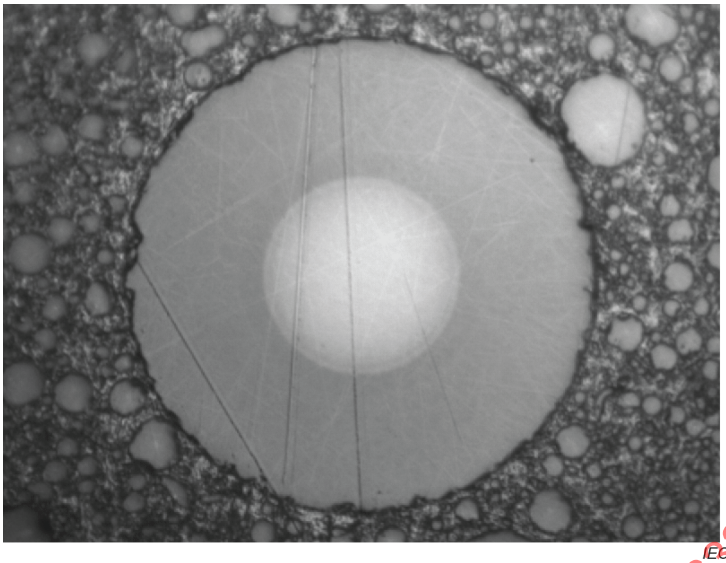


Figure 9 – Image of specimen end face MM14-4

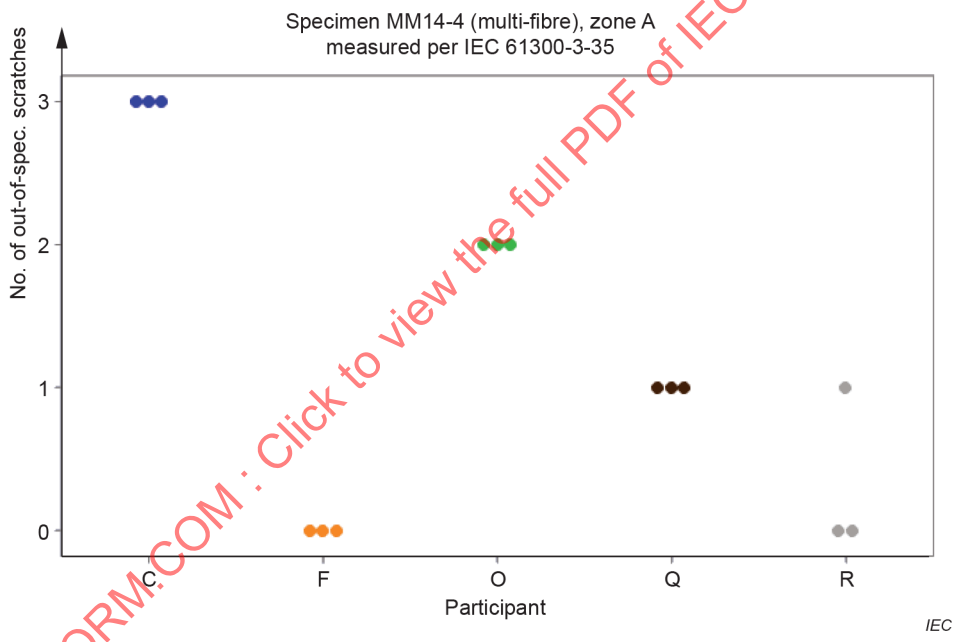


Figure 10 – Number of out-of-specification scratches reported for multimode multi-fibre specimen MM14-4, zone A

Observations of MM14-4

- Overall results show between zero and three reported scratches.
- One out of five participants do not detect scratches while three others report more than one scratch.
- Repeatability within a participant seems better for multi-fibre sample MM14-4 than for single fibre sample MM12.

6.3 Single-mode specimens

For both the multi-fibre and single-fibre, single-mode specimens from finish groups A SM and D SM, which were to contain no visible scratches, no participants reported any scratches. No false fails were reported.

Finish SM groups B, C, E, and F contained specimens with 1 to 3 scratches. Figure 11 to Figure 12 (single-fibre) and Figure 13 to Figure 14 (multi-fibre) contain results from individual specimens which are representative of the observed differences in groups C SM and F MM.

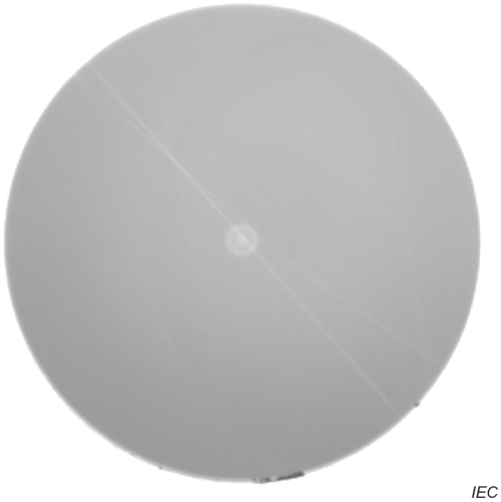


Figure 11 – Image of specimen end face SM9

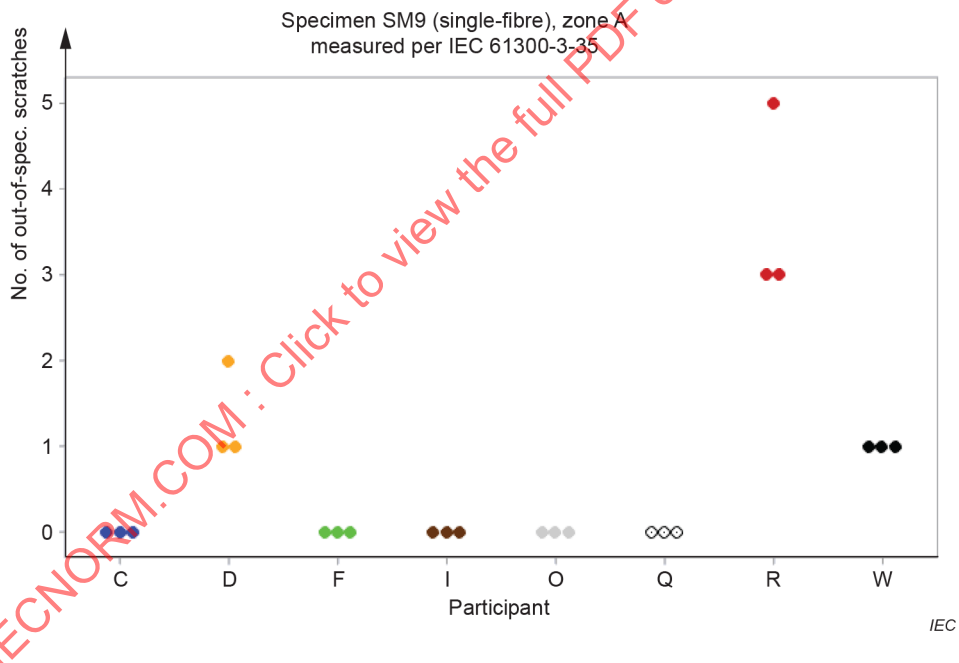


Figure 12 – Number of out-of-specification scratches reported for single-mode single-fibre specimen SM9, zone A

Observations of specimen SM9

- Overall results show between zero and five reported scratches.
- Five out of eight participants do not detect scratches while three others report more than one scratch.

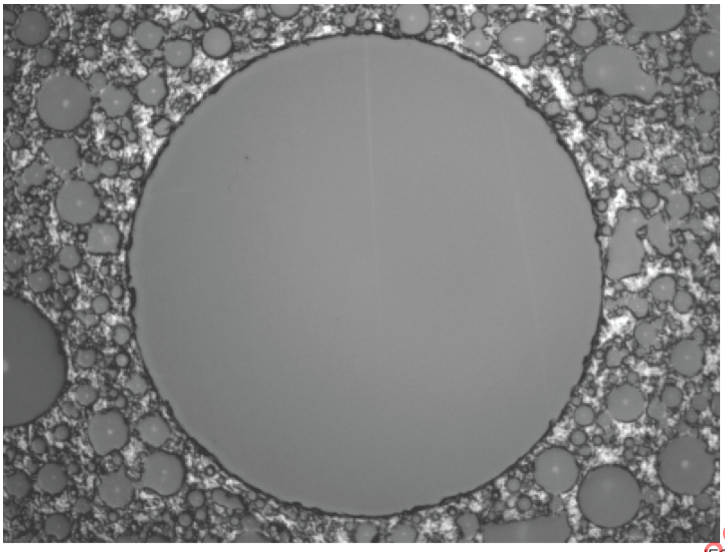


Figure 13 – Image of specimen end face SM15-4

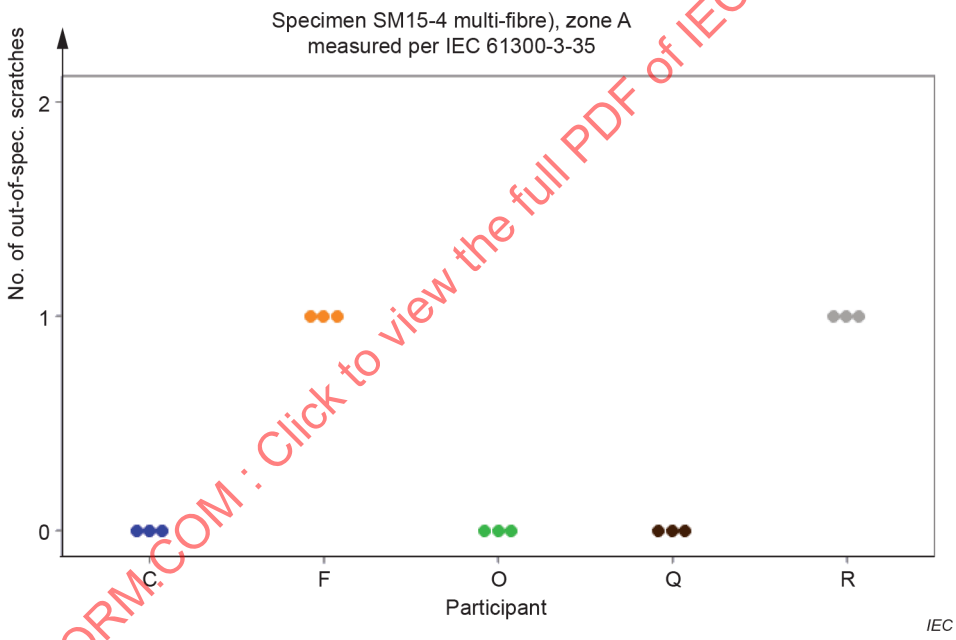


Figure 14 – Number of out-of-specification scratches reported for single-mode multi-fibre specimen SM15-4, zone A

Observations of specimen SM15-4

Three out of five participants do not detect scratches while the two others repeatedly report one scratch.

7 Observations and conclusions

7.1 Multimode observations

- Considerable variability in the reported number of scratches has been observed.
- None of the participants reported out-of-specification scratches in zone A of multimode specimens in groups A MM and E MM (no light or heavy scratches).

- Approximately 25 % of the participants did not report out-of-specification scratches in zone A of multimode specimens in groups B MM and F MM (heavy scratches only).
- Approximately 25 % of the participants reported out-of-specification scratches in zone A of multimode specimens in groups C MM and G MM (light scratches only).
- Approximately 50 % of the participants did not report out-of-specification scratches in zone A of multimode specimens in groups D MM and H MM (light and heavy scratches).
- One participant reported only two out-of-specification scratches in zone A, in total, for all multimode specimens in both the multi-fibre and single-fibre groups.
- The reproducibility of the results, for each participant individually, were better for multi-fibre specimens. All specimens were measured 3 times, but single-fibre specimens were rotated 120° between measurements. The lower reproducibility can be due to the changes in scratch orientation.

Remarks

- Multimode specimens with light, textural scratches had return losses in the 35 dB range, while specimens without these low-level scratches were generally over 50 dB.
- The test specimens generally meet the attenuation requirements of grade Bm.

7.2 Single-mode observations

- Considerable variability in the reported number of scratches has been observed.
- None of the participants reported scratches in zone A on single-mode specimens that did not have any observable scratches.
- Most participants seemed to detect too few scratches on specimens, where the scratches passed through zone A, but not the core. These specimens lack the contrast of scratches, which directly pass through the core.
- Approximately half of the participants detected too few scratches on specimens, where the scratches directly pass through the core. Agreement was generally better compared to the groups with scratches passing through Zone A, but not the core.
- Three participants failed to find any scratches for all single-mode specimens in both the multi-fibre and single-fibre groups.
- The reproducibility of the results, for each participant individually, were better for multi-fibre specimens. All specimens were measured 3 times, but single-fibre specimens were rotated 120° between measurements. The lower reproducibility can be due to the changes in scratch orientation.

Remarks

- Single-mode single-fibre PC specimens with 1 to 3 scratches passing through the core or zone A (outside the core, but with the evanescent field) generally had return losses in the 52 dB to 55 dB range, which were about 3 dB lower than specimens without perceptible scratches.
- Single-mode multi-fibre APC specimens had no distinguishable difference. Return losses were measured to be approximately 68 dB when measured at 1 310 nm wavelength and in the range of 60 to 65 dB at 1 550 nm wavelength.
- The test specimens generally met the attenuation requirements of grade B or grade C.

7.3 Conclusions

The purpose of this round robin was to collect data that would establish the state of the art of visual inspection equipment using method C, automated inspection. Based on the measurement results using the test method described in this document, it could be concluded that agreement among visual inspection equipment is not adequate for scratches that had widths less than 3 µm.

8 Items to be studied

Based on the results and analysing the data, the task force points out the following items to be studied in order to reduce the variability as observed.

1) Revise 61300-3-35:2015.
2) Create a calibration artefact for scratches and preferably also an artefact for defects to set detection limits and confirm compliance with 61300-3-35:2015.
3) Create a certification procedure to confirm compliance with the required reproducibility of IEC 61300-3-35:2015.
4) Once artefact and certification procedure are available, the effectivity is evaluated by another round robin.

Annex A
(informative)

Measurement procedure

The measurement procedure workflow is provided in Figure A.1. It implies every specimen is measured 3 times. Connectors are measured without reinsertion into the device to minimize handling and avoid potential damage, as far as possible.

Measurement instructions were as followed for each specimen from the specimen set.

1) Insert specimen into the device.
2) Focus on the fibre end face (manually or automatically depending on the device capability).
3) If the fibre is not clean, take the connector out of the device, clean it and start from step 1).
4) Perform the auto-tuning of the image if it is provided by the system. This usually includes the adjustment of exposure and viewport.
5) Capture the image if the option is provided by the system. Save the image as .png or .bmp file if possible or use any other format if .bmp and .png are not supported. Name the file "s%smplID_%trial", where "%smplID" is specimen ID and "%trial" is the number of measurement trial.
6) Perform automatic test according to IEC 61300-3-35:2015, where Table 1 should be used for single-mode connectors and Table 4 should be used for multimode connectors.
7) Record the number of scratches detected in zone A (0 µm to 25 µm for single-mode, 0 µm to 65 µm for multimode fibres) and zone B (25 µm to 115 µm for single-mode, 65 µm to 115 µm for multimode fibres). Only significant scratches – those that exceed the limits for the zone defined in IEC 61300-3-35 – are to be counted. These limits are provided in Table A.1.

Table A.1 – Scratch size limits

Connector type	Zone A: significant scratches	Zone B: significant scratches
Single-mode	all detected scratches	> 3 µm in width
Multimode	> 3 µm in width	> 5 µm in width

8) If it is the third measurement trial, inspection of the specimen is finished. Otherwise, rotate connector in the device fixture by approximately 120° if it is allowed by fixture design. Perform next measurement trial starting from step 2).

A results form was circulated among the round robin participants, which includes the following fields that were reported:

- specimen ID;
- connector type;
- fibre type;
- number of significant scratches detected in zone A;
- number of significant scratches detected in zone B.

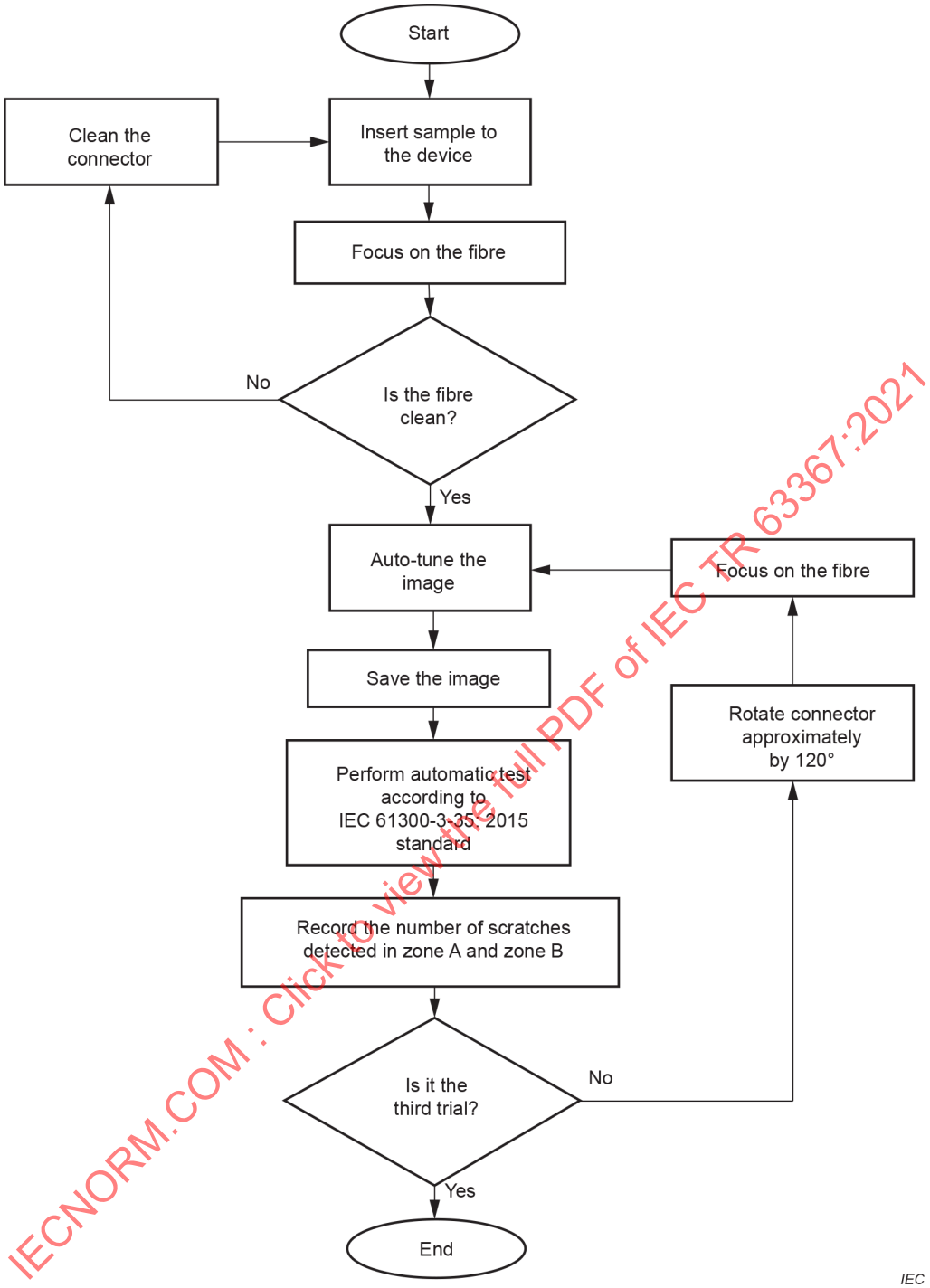


Figure A.1 – Measurement procedure workflow

Annex B
(informative)

Performance and geometry data of test specimens

Annex B provides initial optical performance and end-face geometry data for the test specimens. The attenuation and return loss of the multimode, single-fibre specimens is tabulated in Table B.1 and summarized in Figure B.1 to Figure B.2. End-face geometry data for the multimode, single-fibre specimens is given in Table B.2. A key to identify the multi-fibre interfaces inspected during the round robin is provided in Figure B.3. The attenuation and return loss of the multimode, multi-fibre specimens is provided in Table B.3 to Table B.4, with summary plots shown in Figure B.4 to Figure B.5. The end-face geometry data for the multimode, multi-fibre specimens is given in Table B.5 to Table B.7.

The attenuation and return loss of the single-mode, single-fibre specimens is tabulated in Table B.8 and summarized in Figure B.6 to Figure B.7. End-face geometry data for the single-mode, single-fibre specimens is given in Table B.9. A key to identify the multi-fibre interfaces inspected during the round robin is provided in Figure B.8. The attenuation and return loss of the single-mode, multi-fibre specimens is provided in Table B.10 to Table B.13, with summary plots shown in Figure B.9 to Figure B.10. The end-face geometry data for the single-mode, multi-fibre specimens is given in Table B.14 to Table B.16.

Table B.1 – Initial optical performance of multimode single-fibre specimens

Specimen ID	Attenuation dB	Return loss dB
MM1	0,06	51,1
MM2	0,07	32,1
MM3	0,03	45,1
MM4	0,07	31,3
MM5	0,03	53,0
MM6	0,08	31,2
MM7	0,08	31,7
MM8	0,03	49,5
MM9	0,03	55,7
MM10	0,04	53,5
MM11	0,07	31,8
MM12	0,07	31,5

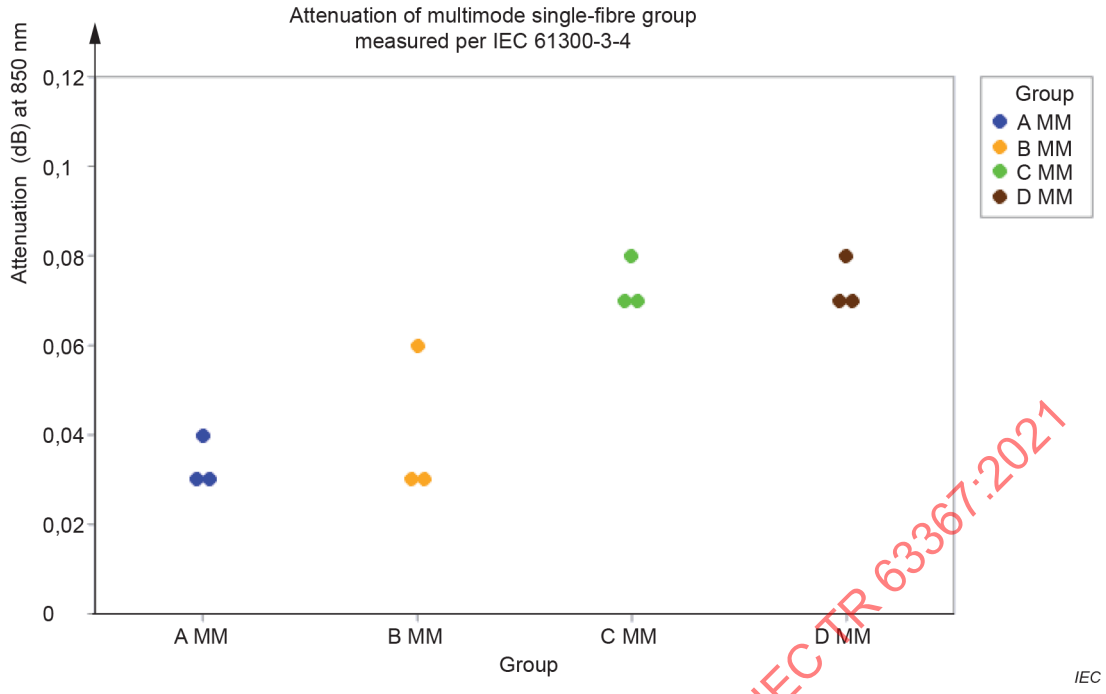


Figure B.1 – Initial attenuation of multimode single-fibre specimens

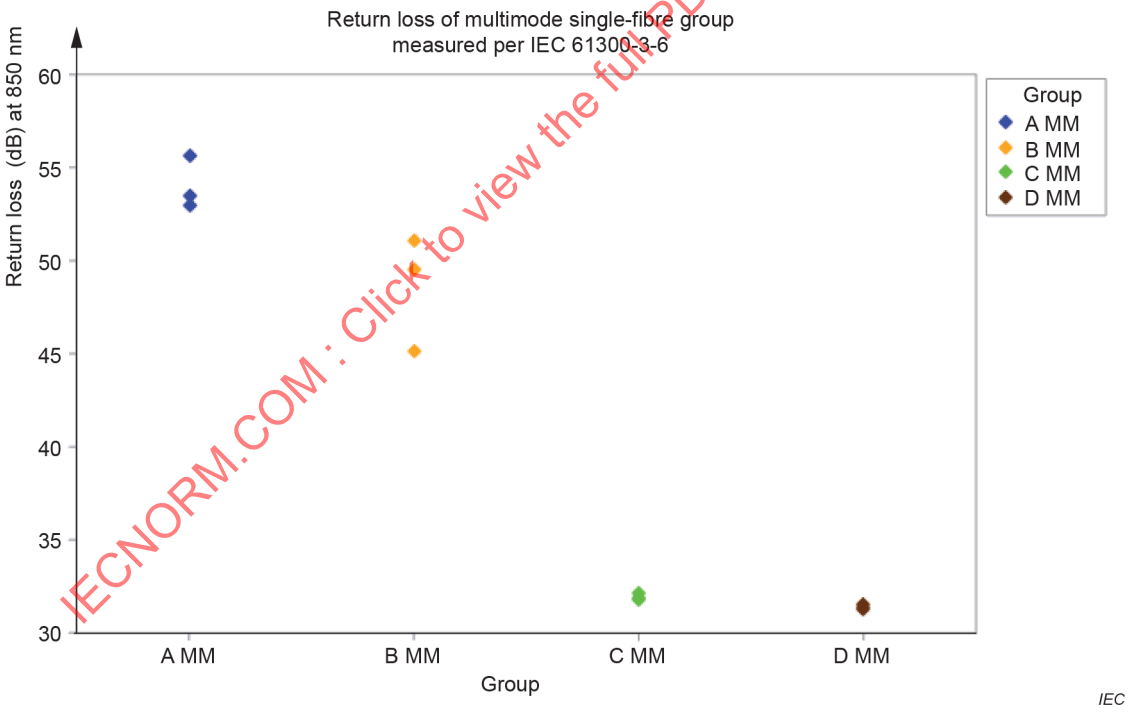
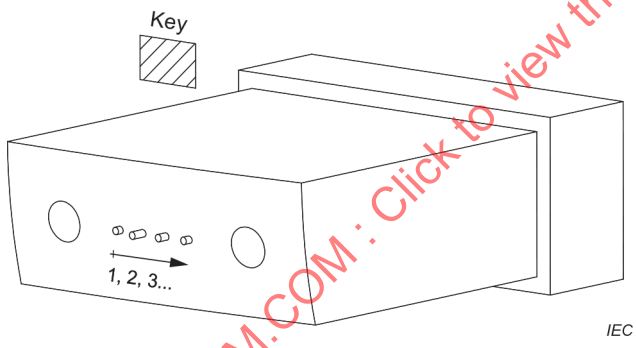


Figure B.2 – Initial return loss of multimode single-fibre specimens

Table B.2 – End-face geometry of multimode single-fibre specimens

Specimen ID	Spherical radius mm	Apex offset µm	Fibre height nm
MM1	18,0	42,4	–38
MM2	7,8	30,8	7
MM3	11,0	37,8	–49
MM4	7,6	31,9	–5
MM5	10,5	47,4	–41
MM6	9,3	46,8	–7
MM7	7,4	19,7	5
MM8	11,2	31,5	–54
MM9	9,0	45,8	–41
MM10	10,1	53,9	–36
MM11	7,0	29,0	2
MM12	7,0	26,5	3

The key in Figure B.3 denotes the polarization feature for MPO connectors per mechanical interface IEC 61754-5.



Ferrule ID	Fibre no.	Specimen interface ID
MM-13	9	MM13-9
MM-14	2	MM14-2
	4	MM 14-4
MM-15	12	MM 15-12
MM-16	8	MM 16-8
MM-17	11	MM 17-11
MM-18	1	MM 18-1
	4	MM18-4
MM-19	6	MM 19-6
	7	MM 19-7
MM-20	1	MM 20-1
	2	MM 20-2

Figure B.3 – Multimode multi-fibre test interface identification key

Table B.3 – Attenuation of multimode multi-fibre specimens

Ferrule ID	Attenuation dB											
	1	2	3	4	5	6	7	8	9	10	11	12
MM-13	0,05	0,10	0,06	0,07	0,05	0,07	0,06	0,06	0,08	0,08	0,08	0,09
MM-14	0,05	0,10	0,07	0,08	0,06	0,08	0,06	0,07	0,07	0,10	0,09	0,08
MM-15	0,03	0,07	0,05	0,04	0,04	0,04	0,03	0,03	0,04	0,06	0,04	0,07
MM-16	0,03	0,06	0,06	0,06	0,06	0,06	0,07	0,05	0,05	0,05	0,06	0,08
MM-17	0,03	0,05	0,05	0,05	0,03	0,04	0,04	0,05	0,06	0,05	0,05	0,07
MM-18	0,06	0,09	0,06	0,08	0,06	0,07	0,07	0,07	0,08	0,07	0,07	0,08
MM-19	0,03	0,07	0,05	0,06	0,06	0,06	0,07	0,06	0,07	0,06	0,06	0,08
MM-20	0,03	0,07	0,04	0,05	0,03	0,04	0,04	0,04	0,05	0,04	0,05	0,06

Table B.4 – Return loss of multimode multi-fibre specimens

h	Return loss dB											
	1	2	3	4	5	6	7	8	9	10	11	12
MM-13	35,2	35,3	35,0	34,9	36,0	35,1	35,9	35,5	35,2	34,5	35,7	36,5
MM-14	34,2	35,3	34,8	34,9	36,0	35,6	36,2	35,7	35,3	34,7	36,3	37,2
MM-15	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1
MM-16	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1
MM-17	34,4	35,1	35,3	35,2	36,4	36,0	36,3	35,9	35,5	34,7	36,3	37,5
MM-18	34,7	35,7	35,5	35,5	36,4	35,9	36,4	36,2	35,9	35,0	36,4	37,5
MM-19	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1
MM-20	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1	58,1

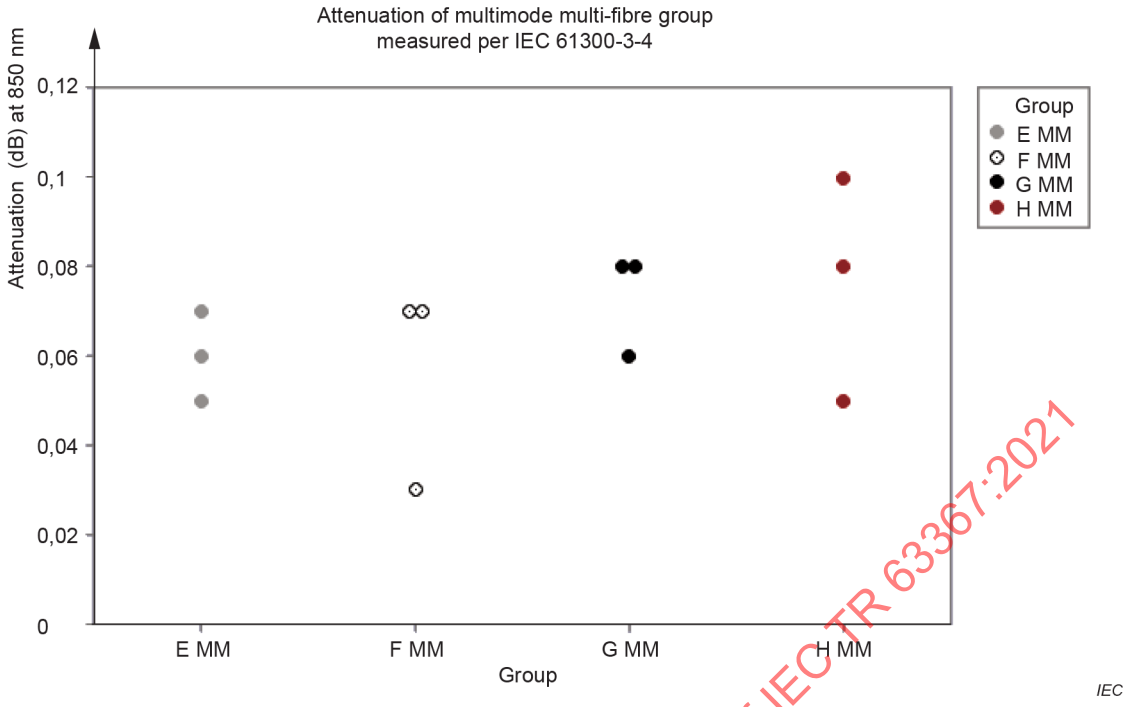


Figure B.4 – Initial attenuation of multimode multi-fibre specimens

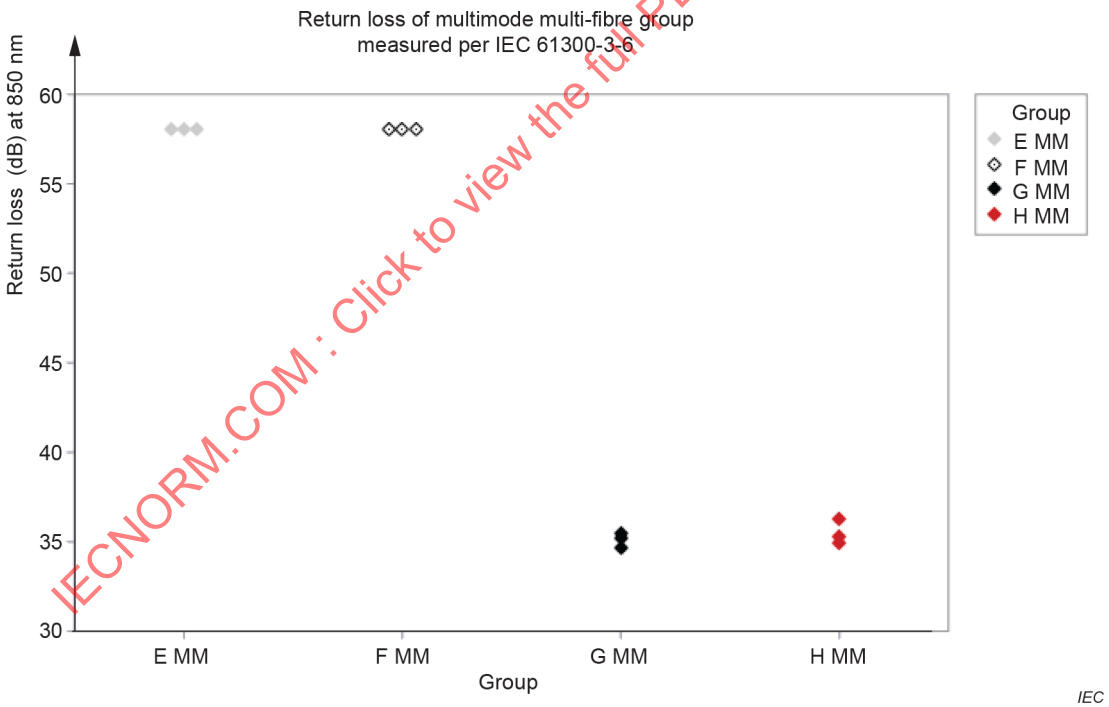


Figure B.5 – Initial return loss of multimode multi-fibre specimens

Table B.5 – End-face geometry parameter of multimode multi-fibre specimens

Ferrule ID	SX[1] °	SY[1] °	RX[1] mm	RY[1] mm	HA[1] µm	CF[1] µm
MM-13	–0,047	–0,032	628 0	298	0,078	0,110
MM-14	0,021	0,062	385 3	308	0,090	0,134
MM-15	0,015	–0,022	495 1	302	0,089	0,138
MM-16	0,020	0,065	447 5	355	0,071	0,139
MM-17	0,007	–0,074	427 3	209	0,151	0,190
MM-18	0,004	–0,056	476 2	260	0,097	0,128
MM-19	0,005	–0,015	582 6	239	0,061	0,100
MM-20	–0,003	–0,038	418 2	268	0,058	0,089
NOTE Refer to IEC 61755-3-31 for parameter definitions.						

Table B.6 – Fibre height of multimode multi-fibre specimens

Ferrule ID	Fibre height µm											
	1	2	3	4	5	6	7	8	9	10	11	12
MM-13	1,58	1,65	1,68	1,70	1,74	1,77	1,75	1,71	1,70	1,67	1,65	1,57
MM-14	1,57	1,66	1,70	1,74	1,76	1,76	1,76	1,74	1,72	1,65	1,59	1,51
MM-15	1,46	1,53	1,57	1,62	1,64	1,63	1,65	1,61	1,60	1,55	1,49	1,40
MM-16	1,74	1,81	1,87	1,90	1,89	1,85	1,85	1,86	1,81	1,74	1,69	1,63
MM-17	1,49	1,55	1,61	1,66	1,71	1,72	1,70	1,69	1,65	1,62	1,55	1,40
MM-18	1,55	1,65	1,67	1,71	1,75	1,76	1,76	1,73	1,72	1,69	1,64	1,56
MM-19	1,42	1,48	1,52	1,54	1,55	1,55	1,54	1,54	1,51	1,47	1,43	1,37
MM-20	1,56	1,61	1,63	1,69	1,70	1,74	1,72	1,68	1,65	1,62	1,60	1,54

Table B.7 – Core dip of multimode multi-fibre specimens

Ferrule ID	Core dip nm											
	1	2	3	4	5	6	7	8	9	10	11	12
MM-13	–14	–12	–13	–25	–19	–16	–19	–15	–16	–14	–19	–34
MM-14	8	2	–1	9	4	8	4	4	3	0	3	–9
MM-15	19	23	23	18	30	30	27	27	10	12	15	1
MM-16	–12	–17	–17	–17	–11	–15	–14	–7	–22	–25	–25	–33
MM-17	–3	–8	–2	–12	–3	0	–1	–7	–7	0	–11	–10
MM-18	–22	–14	–20	–25	–22	–15	–15	–11	–16	–11	–23	–24
MM-19	21	16	18	23	19	17	23	19	8	5	7	9
MM-20	16	17	18	6	22	17	16	17	11	17	10	7

Table B.8 – Initial optical performance of single-mode single-fibre specimens

Specimen ID	Attenuation dB		Return loss dB	
	1 310 nm	1 550 nm	1 310 nm	1 550 nm
SM1	0,23	0,17	53,3	54,2
SM2	0,07	0,04	56,7	56,2
SM3	0,33	0,21	55,9	57,0
SM4	0,06	0,03	52,1	53,6
SM5	0,11	0,06	52,9	54,1
SM6	0,21	0,14	53,9	55,2
SM7	0,08	0,03	56,6	57,7
SM8	0,11	0,07	53,5	54,4
SM9	0,18	0,13	50,0	51,1

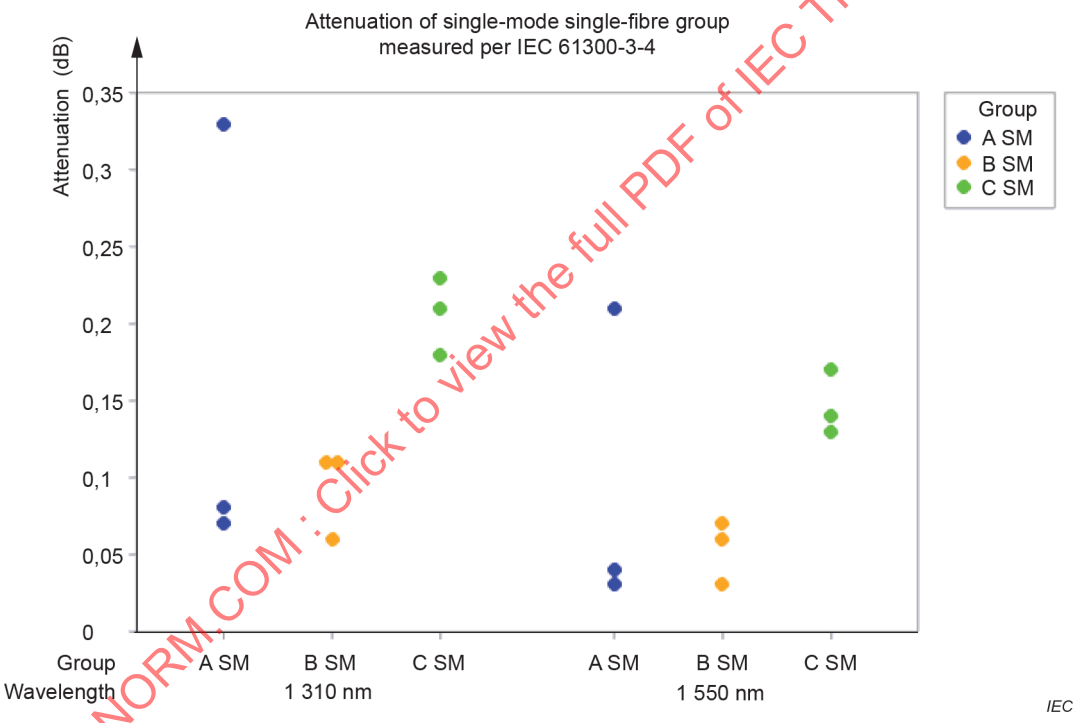


Figure B.6 – Initial attenuation of single-mode single-fibre specimens

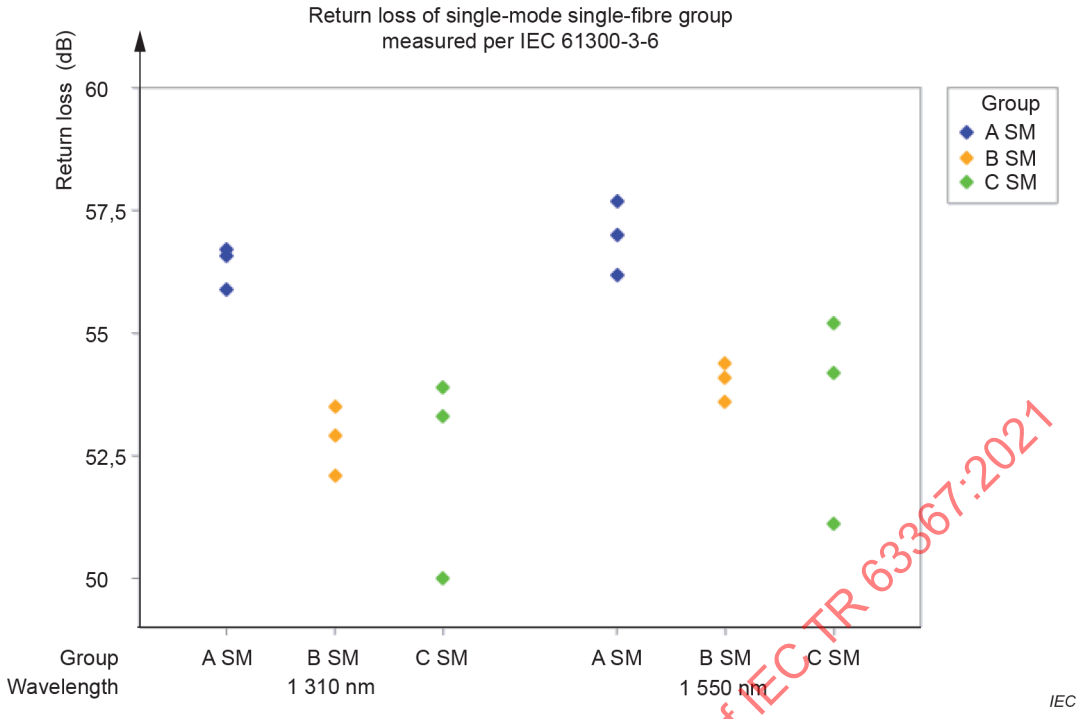
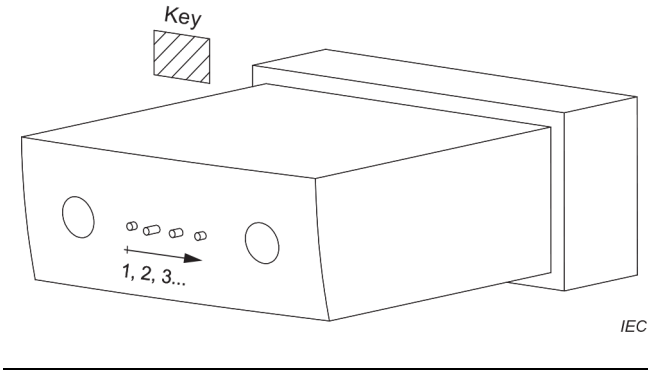


Figure B.7 – Initial return loss of single-mode single-fibre specimens

Table B.9 – End-face geometry of single-mode single-fibre specimens

Specimen ID	Spherical radius mm	Apex offset µm	Fibre height nm
SM1	18,3	28,3	–14
SM2	20,2	18,9	–10
SM3	19,9	6,1	–2
SM4	10,3	38,5	–40
SM5	8,6	36,4	–44
SM6	8,3	17,6	–44
SM7	7,7	24,9	–51
SM8	9,0	42,2	–46
SM9	9,2	34,7	–34

The key in Figure B.8 denotes the polarization feature for MPO connectors per mechanical interface IEC 61754-5.



Ferrule ID	Fibre no.	Specimen interface ID
SM-10	10	SM-10-10
SM-11	1	SM-11-1
	12	SM-11-12
SM-12	11	SM-12-11
SM-13	10	SM-13-10
SM-14	2	SM-14-2
	7	SM-14-7
SM-15	4	SM-15-4
SM-16	10	SM-16-10

Figure B.8 – Single-mode multi-fibre test interface identification key

Table B.10 – Attenuation of single-mode multi-fibre specimens at 1 310 nm wavelength

Ferrule ID	Attenuation dB											
	1	2	3	4	5	6	7	8	9	10	11	12
SM-10	0,08	0,11	0,06	0,10	0,12	0,15	0,02	0,06	0,05	0,08	0,10	0,06
SM-11	0,05	0,03	0,07	0,07	0,04	0,03	0,03	0,02	0,01	0,00	0,12	0,03
SM-12	0,07	0,03	0,05	0,05	0,06	0,05	0,06	0,07	0,15	0,14	0,24	0,15
SM-13	0,09	0,08	0,07	0,07	0,08	0,10	0,05	0,10	0,14	0,12	0,11	0,08
SM-14	0,39	0,28	0,42	0,24	0,25	0,17	0,24	0,21	0,27	0,15	0,34	0,20
SM-15	0,07	0,08	0,08	0,08	0,09	0,09	0,08	0,11	0,16	0,13	0,11	0,11
SM-16	0,06	0,04	0,05	0,06	0,07	0,08	0,05	0,08	0,10	0,11	0,09	0,06

Table B.11 – Attenuation of single-mode multi-fibre specimens at 1 550 nm wavelength

Ferrule ID	Attenuation dB											
	1	2	3	4	5	6	7	8	9	10	11	12
SM-10	0,05	0,00	0,08	0,08	0,09	0,12	0,04	0,07	0,05	0,07	0,05	0,06
SM-11	0,06	0,04	0,07	0,07	0,04	0,05	0,03	0,03	0,03	0,02	0,06	0,07
SM-12	0,05	–0,05	0,05	0,04	0,06	0,06	0,08	0,08	0,11	0,15	0,16	0,19
SM-13	0,07	0,01	0,08	0,08	0,11	0,09	0,08	0,13	0,14	0,12	0,09	0,10
SM-14	0,34	0,09	0,28	0,19	0,19	0,13	0,18	0,12	0,16	0,14	0,22	0,19
SM-15	0,07	0,03	0,09	0,08	0,09	0,08	0,11	0,17	0,16	0,17	0,09	0,11
SM-16	0,08	0,04	0,07	0,07	0,07	0,08	0,07	0,08	0,09	0,13	0,06	0,09

Table B.12 – Return Loss of single-mode multi-fibre specimens at 1 310 nm wavelength

Ferrule ID	Return loss dB											
	1	2	3	4	5	6	7	8	9	10	11	12
SM-10	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0
SM-11	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0
SM-12	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0
SM-13	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	64,0
SM-14	68,0	68,0	68,0	68,0	68,0	68,0	68,0	61,3	68,0	68,0	68,0	68,0
SM-15	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0
SM-16	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0

Table B.13 – Return loss of single-mode multi-fibre specimens at 1 550 nm wavelength

Ferrule ID	Return loss dB											
	1	2	3	4	5	6	7	8	9	10	11	12
SM-10	62,0	62,1	64,0	62,7	64,0	62,8	61,8	62,1	63,9	62,4	60,5	62,3
SM-11	60,3	61,6	62,5	62,9	62,2	63,9	62,6	62,0	63,6	63,0	63,8	62,0
SM-12	62,1	62,4	63,4	64,2	63,6	63,9	63,7	62,9	63,6	62,2	61,2	63,2
SM-13	60,3	62,3	63,1	61,2	63,5	62,8	62,0	62,4	63,4	62,2	61,2	59,9
SM-14	64,1	63,6	64,5	65,1	65,2	68,0	64,0	61,8	64,8	63,9	63,8	63,9
SM-15	60,6	61,3	62,8	63,8	60,4	62,2	61,6	61,1	63,0	62,6	61,3	62,2
SM-16	61,3	63,2	63,5	63,5	63,4	64,4	60,8	63,4	64,0	63,2	60,4	62,7

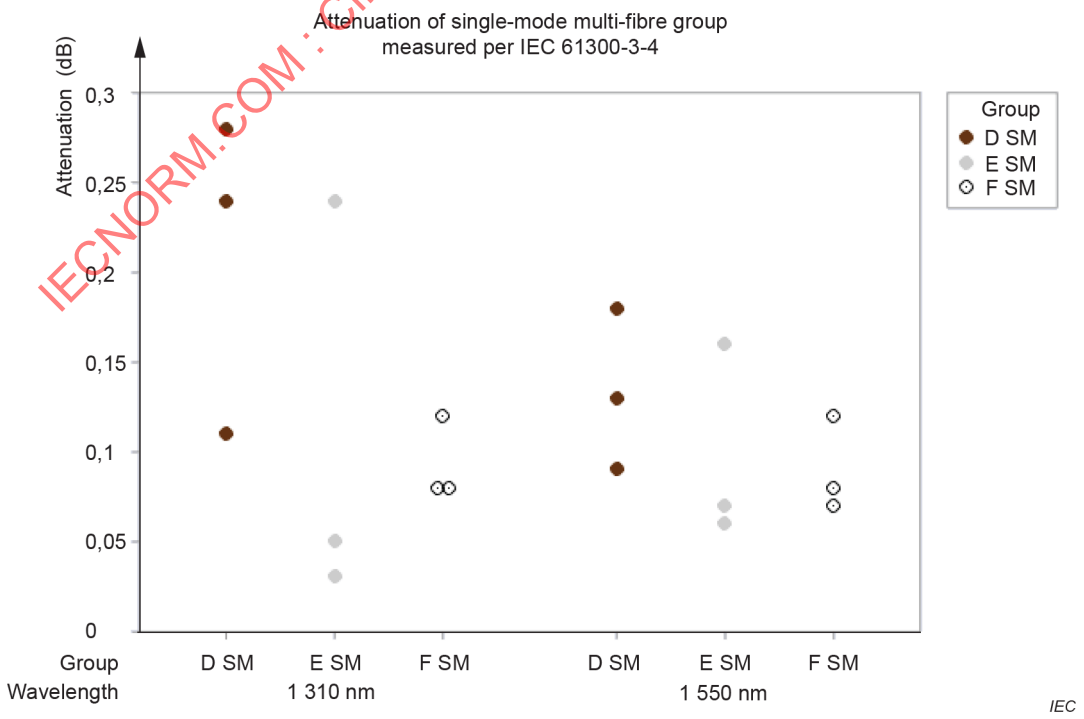


Figure B.9 – Initial attenuation of single-mode multi-fibre specimens

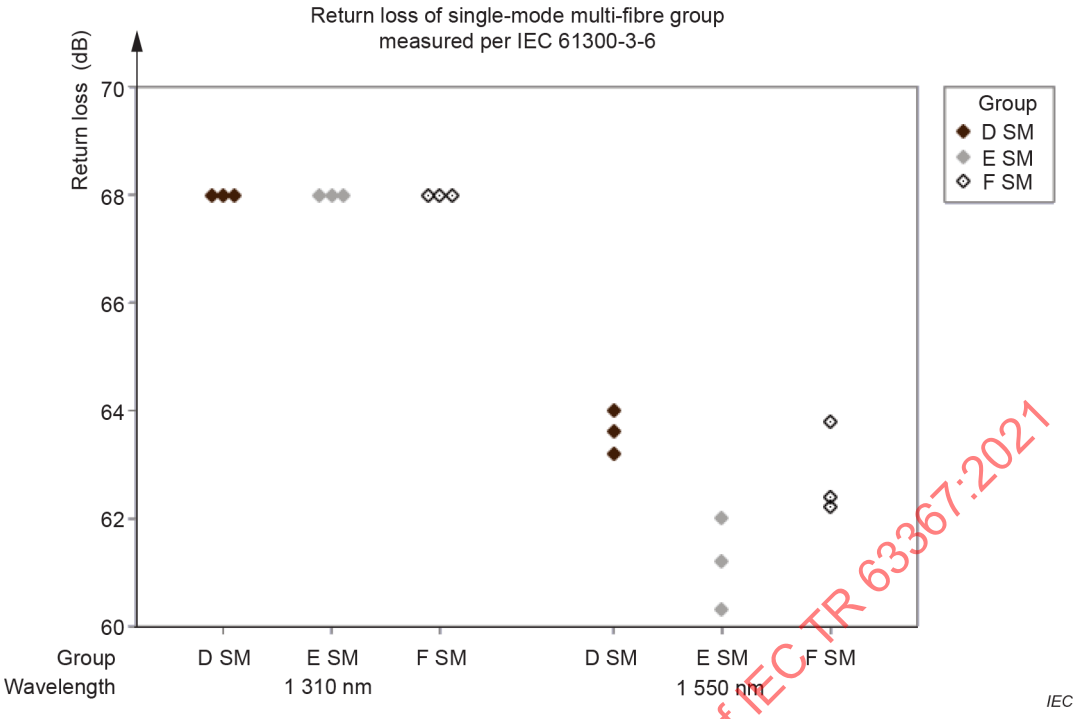


Figure B.10 – Initial return loss of single-mode multi-fibre specimens

Table B.14 – End-face geometry parameter of single-mode multi-fibre specimens

Ferrule ID	SX[1] °	SY[1] °	RX[1] mm	RY[1] mm	HA[1] µm	CF[1] µm	GL[1]
SM-10	–0,005	8,064	8 499	256	0,059	0,082	2,2
SM-11	–0,076	7,967	12 116	101	0,055	0,05	11,5
SM-12	0,020	7,973	22 561	77	0,087	0,062	4,2
SM-13	–0,031	8,038	–56 313	212	0,024	0,027	4,4
SM-14	–0,010	8,180	–16 404	89	0,030	0,011	1,3
SM-15	0,045	8,041	28 802	86	0,083	0,083	7,4
SM-16	0,034	7,993	19 692	72	0,084	0,083	6,2
NOTE Refer to IEC 61755-3-31 for parameter definitions.							

Table B.15 – Fibre height of single-mode multi-fibre specimens

Ferrule ID	Fibre height µm											
	1	2	3	4	5	6	7	8	9	10	11	12
SM-10	1,55	1,58	1,62	1,65	1,66	1,68	1,69	1,70	1,70	1,68	1,62	1,60
SM-11	1,92	1,96	2,02	2,01	1,98	1,98	1,97	1,96	1,97	1,99	1,98	1,93
SM-12	2,12	2,13	2,12	2,12	2,10	2,11	2,07	2,07	2,04	2,01	2,00	1,91
SM-13	1,69	1,69	1,69	1,70	1,70	1,69	1,69	1,69	1,70	1,68	1,66	1,64
SM-14	2,01	2,01	2,00	2,00	2,01	2,01	2,02	1,99	2,01	2,01	1,99	1,98
SM-15	2,07	2,05	2,03	2,06	2,02	2,05	2,06	2,07	2,06	2,03	1,98	1,90
SM-16	2,22	2,20	2,22	2,21	2,22	2,25	2,27	2,27	2,26	2,24	2,21	2,13