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TECHNICAL REPORT

colour inside

Optical fibre cables – Shrinkage effects on cable and cable element end termination – Guidance

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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IEC TR 62959, which is a Technical Report, has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86A/2032/DTR	86A/2058/RVDTR

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

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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- withdrawn,
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- amended.

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INTRODUCTION

Cable shrinkage is sometimes used as a part of the performance criteria for optical fibre cables, including standard glass optical fibres for telecommunication application. However, there is only a partial correlation between shrinkage and other important cable parameters such as temperature performance and optical transmission characteristics, particularly during mechanical and environmental stress, since shrinkage strongly depends on the cable materials, the cable construction and the manufacturing processes.

The environmental performance of optical fibre cables is mainly determined using a suitable temperature cycling test while continuously measuring the change in attenuation during and after the test. Low shrinkage performance is not guaranteed by such a test method, so any cable shrinkage observed during and/or after the temperature cycle test can be used as an additional indicator for the characterisation of cables.

Cable shrinkage should be understood to include shrinkage of the entire cable, shrinkage of cable sub-assemblies such as units, and shrinkage of cable elements. It should also be understood that shrinkage of portions of the cable might be expressed as "growth" of other elements, such as fibres, strength members. Specific issues of cable shrinkage – buffer shrinkage, strength member growth, sheath shrinkage, etc. – should be carefully addressed when applying the principles of this document.

A combination of the passive component design (connectors, passive components, protective housings or cable management components) and cable shrinkage influences the cable/component performance. Excessive shrinkage at the cable/device interface can cause extra process steps and/or extra precautions to be taken at the interface and can cause degradation of the interface in service, for example the failure of strain relief effectiveness at a connector as the sheath shrinks back in use compromising the continuously optimal optical transmission parameters. Component manufacturers use a number of compensations for cable shrinkage in the design or assembly process of their components and will often select cables used in finished components for their low shrinkage performance. On the other hand, shrinkage can be compensated by installation technique.

To cover all relevant aspects of cables to be terminated, the recommended tests for performance evaluation of cables for different termination cases in addition to the optional tests for evaluation of shrinkage effects are included in this document.

This study into cable shrinkage was triggered by a CENELEC/TC86 BXA liaison letter sent to IEC/SC 86A in April 2016. The letter pointed out observed inconsistencies in indoor cable standards from a user point of view and asked for their concerns and recommendations to be addressed. The main subject was that jacket shrinkage should be a specified parameter for all indoor cables that are normally terminated by connectors, passive components or closures/enclosures.

A correspondence group in IEC/SC 86A/WG 3 was formed in 2016 to address issues about cable shrinkage. After discussion about relevant issues, cable shrinkage tests were performed, and the test results were collected and recorded. Annex A shows these test results and Clause 7 gives the conclusions of the cable shrinkage study. Generally, optical fibre cable types with a small outer diameter were involved in shrinkage testing. The results of different cable types from only a few cable manufactures were included, hence the number of cable types was limited and does not represent all cable types in the worldwide market. Subsequent work was done on recommendations for performance evaluation of cables to be terminated with connectors.

OPTICAL FIBRE CABLES – SHRINKAGE EFFECTS ON CABLE AND CABLE ELEMENT END TERMINATION – GUIDANCE

1 Scope

This document, which is a Technical Report, provides information on cable shrinkage characterisation of optical fibre cables that consist of standard glass optical fibres for telecommunication application. The characterisation is directed to the effects of cable shrinkage or cable element shrinkage on the termination of cables. Shrinkage can or cannot be a concern depending on the method of termination. Examples of different cable termination cases are included and described. Tests for the evaluation of cable shrinkage are recommended that can be used as indicators, and shrinkage classification by several grades are given.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60794-1-1, *Optical fibre cables – Part 1-1: Generic specification – General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60794-1-1 and the following apply.

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

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

3.1
shrinkage
irreversible contraction after extrusion of plastic materials caused by heating or over time at ambient temperature

Note 1 to entry: The irreversible contraction in the direction of the cable axis is usually called "cable shrinkage".

Note 2 to entry: This behaviour is also called "shrinkback".

3.2
thermal contraction
decrease in length of an element or assembly when subjected to a temperature increase or decrease

3.3
thermal expansion
increase in length of an element or assembly when subjected to a temperature increase or decrease

3.4
cable end effect
effect that occurs at the cable's ends

Note 1 to entry: End effects can take different forms. For example, during winding/unwinding or over time, the cable elements can move at the ends relative to the sheath.

4 Abbreviated terms

CTE	coefficient of thermal expansion
FMC	field mountable connector
FMS	fibre management system
HFFR	halogen free flame retardant
LSZH	low smoke zero halogen
ODFM	optical distribution frame module

5 Characteristics of optical fibre cables

5.1 General

For continuously good optical cable performance, the materials, design and manufacturing of the cable should be optimised. Subclauses 5.1 to 5.5 give detailed information about these factors.

5.2 Cable materials

5.2.1 Plastic materials

Many different plastic materials, primarily thermoplastics, are optimised for commercially available extrusion processes. Some are specifically promoted as having a low post-extrusion shrinkage. Nonetheless, all extruded plastic materials expand and contract reversibly and shrink irreversibly.

It should be noted that plastic materials used for optical fibre cables have to meet many more requirements beyond shrinkage, depending on customer technical requirements and local market conditions and regulations. This can include, but is not limited to: free of hazardous substances and halogens, high tensile strength, good UV resistance, good weathering and abrasion resistance, high flame retardancy, high thermal stability, good bend behaviour, easy strippability of the cable sheath and fibre buffer and several other attributes.

5.2.2 Reversible thermal expansion and contraction

Temperature changes cause thermal expansion or contraction of materials. Each material has a certain linear coefficient of thermal expansion (CTE). Typical coefficients of ten materials are listed in Table 1.

Table 1 – Linear coefficients of thermal expansion of materials (informative)

Material	Linear coefficient of thermal expansion $\times 10^{-6}$ K^{-1} [a]	Reference of data (see Bibliography)	Typical application in cables
Aramid [b]	−5	[1]	Strength member for optical fibre cables
Copper	+17	[2]	Power conductor in power and hybrid cables
E glass [c]	+5,5	[2]	Central strength member for optical fibre cables
Glass (fused silica)	+0,5	[2]	Optical fibre
Polybutylenterephthalate (PBT)	+108 to +144	[3]	Tube for fibres in optical fibre cables
Polyethylene (PE)	+100 to +200	[2]	Sheath
Polypropylene(PP)	+58 to +100	[2]	Tube for fibres in optical fibre cables
Polyvinylchloride (PVC)	+70 to +210	[4]	Sheath
Low-carbon steel [d]	+9,9	[5]	Strength member for optical fibre cables
Stainless steel (18-8)	+17	[2]	Armour

[a] To +20 °C reference.

[b] Longitudinal to the fibres.

[c] Same coefficient for glass-reinforced strength member with thermosetting resin coating (glass > 80 % weight).

[d] Ferritic – 410.

Because different materials are used within cables, when the temperature changes, the cable elements and the sheath expand or contract differentially. If the elements cannot move freely, forces are generated within the cable. If the fibre is stressed by such forces, then optical performance can degrade temporarily. After the temperature reverts to its original value, cable elements return to or close to their original lengths, unless they have undergone shrinkage or are restrained by internal coupling. This reversible thermal material dimension change is seldom independently addressed as a cable characteristic.

Annex B describes a suitable test method for determination changes in cable sheath length, and optionally cable's elements, on short cable samples during a climatic exposure test. Information about the thermal expansion and contraction can be helpful when classifying a cable and to understand the higher attenuation observed during climatic tests.

5.2.3 Irreversible thermal contraction (shrinkage)

Irreversible thermal contraction is specifically relevant for extruded plastic materials in optical fibre cables. During the cooling stage of an extrusion process, the polymer orientation is "frozen". If the extruded material is exposed to a high temperature, or kept for a long time at room temperature, the frozen-in polymer orientation can relax, and the extruded plastic material can shrink in direction of the extrusion in an irreversible way [6][1]. The amount and speed of post-extrusion shrinkage can be influenced significantly by the process parameters during extrusion and by the choice of the base material. Zero or negligible shrinkage can be achievable in some cases.

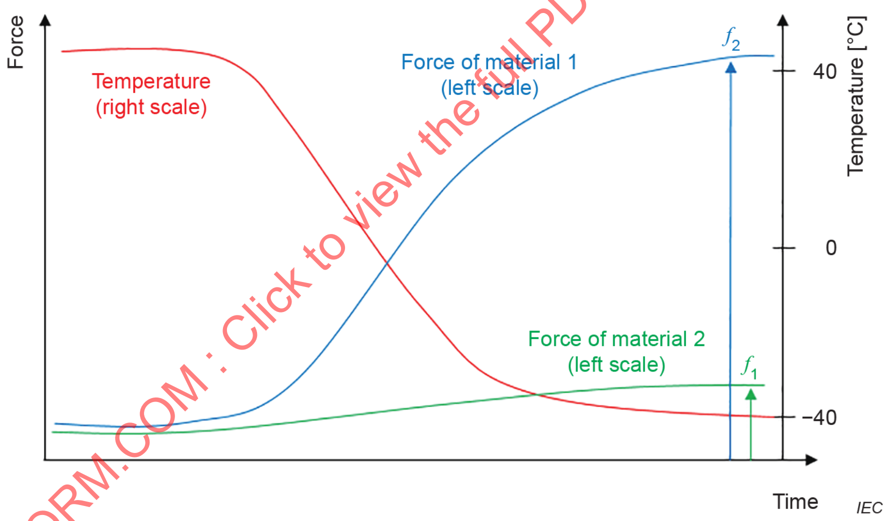
1 Numbers in square brackets refer to the Bibliography.

This post-extrusion shrinkage can be reduced by the inclusion of strength members coupled to the plastic. The more rigid the strength members are and the more tightly the plastic materials are extruded onto them or otherwise coupled, the more the force caused by shrinkage is compensated for by the strength members and the more the potential shrinkage is reduced. If the fibre is stressed by such a force within the cable, then optical performance can degrade permanently.

5.2.4 Forces between cable elements caused by thermal changes

Thermal changes cause forces between cable elements that are made of different materials due to different CTEs as well as different shrinkages. Such forces can induce stress on the optical fibres within the cable. In a general sense, the higher the shrinkage or interactive force, the more likely attenuation can be elevated (see 5.5.2). This shrinkage force is a good indicator for the stress applied to the fibre, but still it is not the only influencing factor (see 5.5.3).

For measurement of the force of a polymer material caused by temperature changes, dynamic-mechanical analysis (DMA) can be used. A defined material sample is fixed at two points and the force between those two points is continuously measured while the temperature is changed. After exposure at high temperature and during lowering of the temperature, a pulling force between the two points is generated resulting from the shrinkage of the material. As shown in Figure 1, as a qualitative example, the measured forces (f_1, f_2) of two tested polymer materials are significantly different (by approximately a factor of 5 when the temperature is reduced to −40 °C).



Key

f_1 measured force of material 1

f_2 measured force of material 2

Figure 1 – Qualitative example of force during decreasing temperature of two polymer materials

Another method is described in ISO 14616 [28] for heat-shrinkable films where shrinkage stress and contraction stress can be determined using a heating hood, a bracket, a force meter and shrinkage measurement.

5.3 Cable design

As well as the materials used and the extrusion processes, the cable construction itself can have a marked influence on the shrinkage performance of a cable.

Excessive shrinkage of cable elements and cable sheath can have severe impact on optical fibre cables due to compressive forces applied to the fibres, especially in cable designs not providing a rigid longitudinal reinforcement member. In a cable, the shrinkage of one element/layer is rarely independent from another. Friction between the different elements plays a major role and the behaviour of a cable end is different than the middle of the cable.

A buffer, cable element or sheath can be manufactured using pressure extrusion or tube extrusion. In pressure extrusion, the melted plastic contacts the inner cable elements long before it reaches the die end. This is done at a high pressure to ensure good adhesion of the plastic material. Generally, such manufactured plastic layers have low shrinkage after extrusion but transfer high forces due to a tendency to shrinkage to the underlying cable elements. If adhesion is not desired or necessary, then tube tooling and tube extrusion are used instead. A plastic layer extruded as a tube has the benefit that the thermal expansion or contraction of the plastic causes no, or only limited, forces on the underlying cable elements. Therefore, the cable design has a major impact on what level of shrinkage leads to an increased attenuation.

The fibre should not be overly stressed by reversible thermal expansion and contraction or by irreversible thermal contraction (shrinkage) of cable elements and cable sheath. Enough space for the fibre in a cable (e.g. buffer or tube) does not necessarily restrict the stress on the fibre thoroughly. A tight buffer can typically limit the stress to the fibre effectively and better than a loose buffer (semi-tight). Multi-fibre loose tubes that are often used in multi-fibre cables contain space for the primary coated fibres and jelly or water swellable materials. These loose tubes can restrict stress to the fibres to an acceptable level. On the other hand, fibre overlength storage room and enough space for fibre bends in, for example, a passive component or splice cassette can limit the stress on the fibre effectively.

5.4 Basic cable types

Table 2 provides typical characteristics of two basic cable types, indoor and outdoor, that have different key design features, different key performance parameters and different applications. The typical characteristics for the two basic cable types in Table 2 are not complete and are not applicable in all cases. As well as these two basic cable types, indoor-outdoor cables exist for universal or partly restricted indoor and outdoor use – see IEC 60794-6 (all parts) [21].

Table 2 – Typical characteristics of indoor and outdoor cables

Characteristic	Indoor cables	Outdoor cables
IEC cable standard series	IEC 60794-2 (all parts) [15]	IEC 60794-3 (all parts) [18], IEC 60794-4 (all parts) [19], IEC 60794-5 (all parts) [20]
Key cable design features		
Number of fibres per cable	Low	High
Cable construction	Flexible, non-armoured, easy strippable	Stiff, armoured, robust
Cable outer diameter	Small	Large
Key performance parameters		
Water blocking	Not required	Required
UV resistance	Not required	Required
Resistance against humidity	Not required	Required
Other environmental exposure [a]	Not required	Not required
Small bend behaviour	Required	Not required
Reaction to fire	Required	Not required
Applications		
Type of installation	Laying into cable containment, pulling into a duct	Pulling into a duct, direct buried, lashed aerial or blowing
Cable length	Short	Long
Cable end locations	Distribution rack, box, outlet	Closure, street cabinet, distribution rack
Critical termination features	Cable element fixing, kink protection	Cable element fixing, storage of fibre over-length, sealing
Fibre termination	With connector, with splicing	With splicing, with hardened connector
Network type	Building cabling, home and office cabling, data centre, central office	Core and access network, FTTH, campus cabling

[a] Other environmental exposure means, for example, exposure against various fluids, exposure against mould growth, exposure from rodents, birds or insects, exposure to the effects of freezing water (ice), etc.

5.5 Cable performance

5.5.1 General

The various product standards according to IEC 60794-2 (all parts) [15], IEC 60794-3 (all parts) [18], IEC 60794-4 (all parts) [19], IEC 60794-5 (all parts) [20] and IEC 60794-6 (all parts) [21] specify the performance requirements of optical fibre cables. These requirements reference standardised mechanical and environmental test methods according to the IEC 60794-1-2x (all parts).

Information about old and new references of cable test methods is given in Annex K.

5.5.2 Optical performance during temperature changes

Generally, the optical performance of manufactured cables is determined by measurement of the attenuation (dB) or the attenuation coefficient (dB/km) at ambient temperature. Because the cables are exposed to changes of temperature in real applications, the optical performance during such changes is an important quality characteristic. A temperature cycling test while measuring the change in attenuation during and at ambient after the test provides that information. Each cable type should be tested and specified for a certain temperature range.

Method F1 according to IEC 60794-1-22 [13] tests the optical performance of a typical long cable length (e.g. 1 000 m) on a cable drum or in a coil and without termination of the cable ends. This method tests the optical performance of the cable itself and does not consider terminated cable ends.

Dedicated methods, for example Method F12 of IEC 60794-1-22 [13], for testing the optical performance of cords and cables to be terminated with connectors exist, where the cable is tested as the final product, for example a patch cord (see Annex A), or with cable elements fixed at the cable ends (see Clause D.7).

Nonetheless, even acceptable attenuation results of these test methods do not guarantee, or even evaluate, a small sheath shrinkage or a small protrusion of cable elements for any cable designs. In some application cases, shrinkage requirements can be necessary to limit extensive movement of cable elements (see Clause 9).

5.5.3 Cable shrinkage characteristic

Low cable shrinkage does not necessarily influence the attenuation performance of a cable because they are not directly linked to each other. Likewise, high cable shrinkage does not necessarily cause poor attenuation performance of a cable. For example, a certain shrinkage of the cable sheath can cause different forces to the inner cable elements depending on the Young's modulus of the sheath material, on the volume of the material and on the cable construction. As explained in 5.2.4, the resulting force caused by shrinkage is also an important indicator of the performance of the cable. Additionally, a correlation of cable shrinkage to attenuation performance is not possible between different cable types nor between similar cable types manufactured by different manufacturers. For instance, a 5 mm sheath shrinkage on a single fibre indoor cable can affect performance differently than a 5 mm sheath shrinkage on an outdoor loose tube cable. Similarly, manufacturer A's ∅2 mm indoor cable with 5 mm of shrinkage can affect performance differently than manufacturer B's ∅2 mm indoor cable with the same amount of shrinkage. For this reason, this document stresses the importance of attenuation measurement during change of temperature and only recommends the cable shrinkage test as an indicator (example can be seen in Table D.1).

During testing of a cable sample length, the cable elements can move at each cable end but less so in the middle of a cable length. A longer cable length typically shows a shrinkage value at the ends that is lower than one linearly calculated from the shrinkage of a shorter cable length. This effect is known as "cable end effect".

Beyond attenuation issues, physical shrinkage, or element protrusion (due to shrinkage or other factors) should be considered in the cable design and termination. Connectors on the end of cables – either indoor or outdoor – can be damaged by shrinkage or protrusion. Termination of cables in closures or boxes can suffer loss of integrity or damage to fibres or components by sheath shrinkage or strength member protrusion. Tubes or buffers within trays or other routing devices can be affected by kinking due to protrusion. The amount of shrinkage or protrusion and installation methods to address this potential should be considered and evaluated.

NOTE The level of shrinkage depends on the materials used, the cable construction and the parameters of the applied extrusion process as described in 5.2 and 5.3. The materials, the cable construction as well as the extrusion processes have to be defined and can be optimised for a number of attributes, including shrinkage. The goal is to achieve an optimal combination of the materials used, the cable construction and extrusion processes during manufacturing so that the optical performance is stable during and after the specified mechanical and thermal loads. Shrinkage generally cannot be avoided but can be restricted to a certain level.

5.5.4 Cable shrinkage during connector termination process

A cable can be exposed to high temperature during a termination process step, when connectors using epoxy in ferrule's require a high temperature to cure. The cable end can be exposed to high temperature conducted there by parts in the rear of the connector to which the cable is fixed. The termination process should be designed to avoid subjecting the cable to conditions outside of its specified parameters.

6 Test methods for cable shrinkage

6.1 General

Test methods for shrinkage should test the desired characteristic of the cable as realistically as possible and lab technicians should be able to perform them easily and economically. Thus, test methods are a compromise between realistic performance simulation and having simple test procedures. In the case of shrinkage testing, two different test methods are proposed in 6.3 and 6.4.

6.2 Conditions before shrinkage testing

Shrinkage is strongly dependant on the thermal and mechanical history of the cable. Some shrinkage can occur after cutting the sample from the drum, during storage of the cable in the manufacturing plant and warehouse, during transportation or during preparation and preconditioning of the cable before testing. If the shrinkage happens partly before testing, the subsequent shrinkage test cannot give a reliable result.

Therefore, the conditions between manufacturing and the shrinkage testing should be considered. The storage, preparation and preconditioning should influence the shrinkage as little as possible so that the measured shrinkage faithfully represents the worst case and is also reproducible.

During the test, cable sheath materials can stick to the supporting elements in the climatic test chamber. This would prevent the cable from further shrinking. Special attention has to be taken to guarantee a free movement of the cable during the test.

This recommendation is for testing purposes only and should not limit intentional manufacturing steps to assist in the minimization of cable shrinkage of finished good products (such as preconditioning before shipment to a customer).

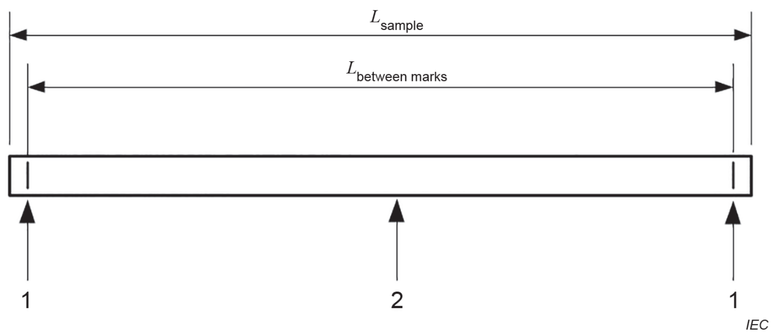
6.3 Test method F11

The first test method F11A is suitable for cables where the fibre or buffered fibre and the sheath of the cable are intended to be fully terminated into a connector at one or both cable ends. A short cable sample length is well-suited for absolute measurement of the change in sheath length caused by shrinkage because it can be put into a typical chamber uncoiled, and reproducible measurements can be achieved.

The limitation of shrinkage measurement performed on a short cable sample is that a longer cable sample length will show greater absolute shrinkage values. Nonetheless, the largest relative shrinkage (in %) on short cable samples can be measured to determine the shrinkage grade of the cable. Comparative testing should always use samples of the same length.

Method F11A in accordance with IEC 60794-1-211[2] [14] defines sheath shrinkage testing on a cable sample of 1 m length measuring the absolute change in length of the cable sheath. The sample lengths are specified as 1 m or 150 mm in nominal length. Before temperature cycling, the cable samples are cut into the appropriate length (e.g. 1 050 mm for nominal 1 m length; 160 mm for nominal 150 mm length) and the nominal length for shrinkage measurement (e.g. 1 000 mm or 150 mm) is marked (or otherwise indicated, per F11A) on the sheath as shown in Figure 2. Then the samples are temperature cycled and, after a recovery period, the length of the samples is measured again. The difference of the length between the marks before and after temperature cycling is the value of the shrinkage.

[2] Under preparation. Stage at the time of publication: IEC/CFDIS 60794-1-211:2020.



Key

1 mark on cable sheath

2 cable sample

Figure 2 – Cable sample for shrinkage testing according to Method F11

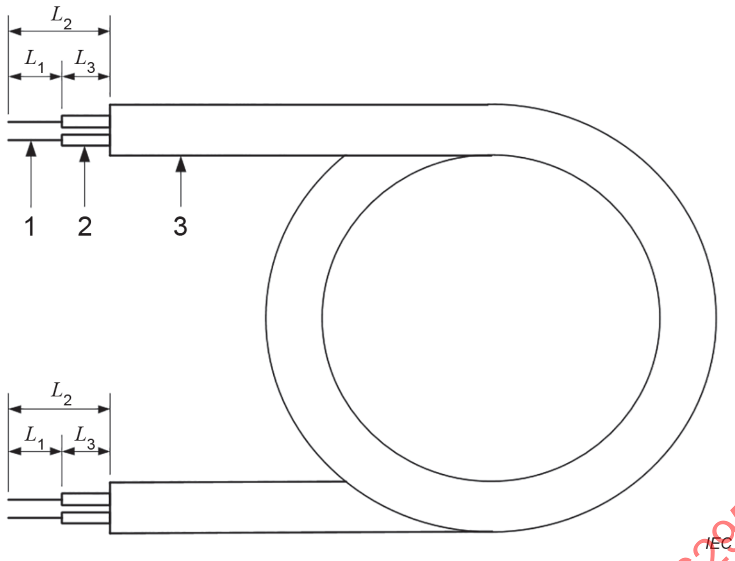
The second test method F11B is defined for sheath shrinkage testing for general purpose using a sample length of 150 mm. A mark is put on the cable sheath close to each sample end. The initial test cable sample distance between the marks are measured. Alternatively, the sample may be cut to length and the length between the cut sheath ends measured. The sample is put in the oven at the (constant) temperature and for the time period specified in the detail specification. After a recovery period, the final distance is measured. The difference of the distance between the marks before and after temperature exposure is the (absolute) value of the shrinkage.

6.4 Test method F17

All cables have a memory effect in the form of coils and are elastic depending on the applied force that makes reproducible measurements from one end to the other end on a longer cable sample (e.g. 10 m or longer) very difficult or impossible. Therefore, measurement of the fibre or cable element protrusion at both ends is a suitable and simple alternative.

The advantage of this method is that the change in protrusion length can be directly compared with the capability to accommodate this change of protrusion length in the application situation. The limitation of this method is that the absolute change of the cable element and sheath lengths cannot be determined.

Method F17 according to IEC 60794-1-22 [13] defines shrinkage testing on a cable sample with a minimum length of 10 m by measuring the fibre and indirectly the buffered fibre or fibre tube protrusion at both ends. Before temperature cycling, the specified cable sample is coiled in loose coils, each cable end is stripped exposing the fibres and buffered fibre or fibre tube and the initial fibre protrusion lengths are measured as shown in Figure 3. Then the sample is temperature cycled and after a recovery period, the protrusion lengths are measured again at each end. The change of the protrusion lengths are calculated using the values measured before and after temperature cycling.



Key

1 fibre or bundle of fibres

2 secondary fibre protection or fibre tube

3 cable sample

L_1 fibre protrusion length from the edge of the secondary fibre protection or fibre tube

L_2 fibre protrusion length from the edge of the cable sheath

L_3 not a measured length but can be calculated from L_2 and L_1

Figure 3 – Cable sample for fibre protrusion testing according to Method F17

In Figure 3, the protrusion of the secondary fibre protection or fibre tube is represented as length L_3 that is not measured according to the test Method F17 but can be calculated as L_2 minus L_1.

7 Conclusions of the cable shrinkage study

7.1 General

A correspondence group in IEC/SC86A/WG3 worked on several issues relating to cable shrinkage between 2016 and 2018. Amongst others, one issue in this study was to perform cable shrinkage tests and to collect and record the test results. Clause 7 gives the conclusions of the cable shrinkage study. Shrinkage test results are given in Annex A.

Specifically important is the fact that similar and different cable types can have different shrinkage behaviours and have demonstrated different shrinkages. Therefore, the conclusions given in Clause 7 should be regarded only as possible behaviour of the tested cable types.

7.2 Conclusion for simplex cables

The following sheath shrinkage behaviour could be observed.

- In certain temperature ranges, the higher the upper temperature, the higher the shrinkage.
- Temperature cycling induced higher shrinkage than aging at a continuous high temperature when using the same high temperature.
- The first few cycles, typically between 1 and 4, induced the largest part of the shrinkage compared to the cycles which followed.

- Different soak times (1 h and 4 h) used for temperature cycling between low and high temperature resulted in almost the same shrinkage values.
- On short cable samples, larger relative shrinkage (in %) can be measured than on longer cable samples. Shrinkage is not linear along the whole cable length. Cables show a "cable end effect" (see 5.5.3).
- The sheath length measured at low and high temperature is different to that when measured at ambient temperature after temperature cycling (as is usually done). This explains why the largest change in attenuation is measured during the low temperature phase when performing a change of temperature test (see 5.2.2).
- The level of shrinkage and reversible thermal expansion and contraction is not linked to each other.
- A uniform correlation between shrinkage and optical performance could not be found. Nonetheless, a low shrinkage value increases the chance that the cable also has a good optical performance. The additional parameters that influence optical performance other than shrinkage are given in 5.5.

7.3 Conclusion for loose tube cables

The following cable element protrusion behaviour could be observed:

- The first few cycles, between 2 and 4, induced the largest part of the fibre protrusion change compared to the cycles which followed (i.e. after 8 and 12 cycles).
- Longer sample lengths (5 m, 10 m and 20 m) often showed a longer fibre protrusion change (almost a linear correlation). Only one stranded loose cable type showed the same fibre protrusion change when using a 10 m and 20 m sample length.
- The change of fibre protrusion measured from the edge of the fibre tube and measured from the edge of the cable sheath were often very similar or the same showing that little or no change of the loose tubes protrusion was induced.
- The change of protrusion of the central strength members was moderate and smaller than the fibre protrusion.
- The change of fibre protrusion values vary significantly between the different cable types.

The correlation between shrinkage respectively fibre protrusion and optical performance was not studied for loose tube cables.

8 Termination cases of optical fibre cables

8.1 General

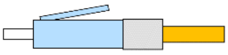
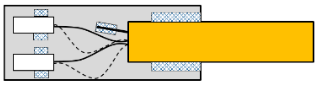
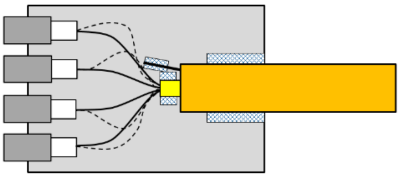
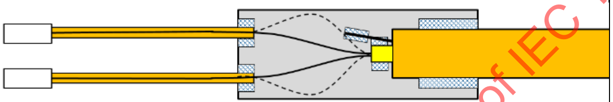
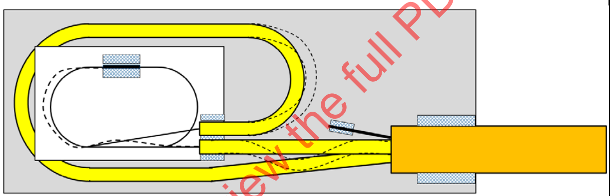
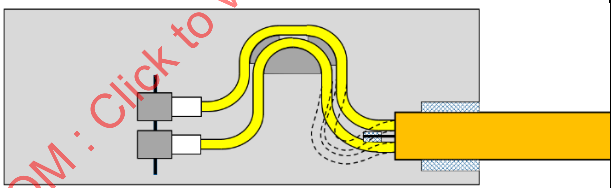
All optical fibre cables are terminated at each cable end in one way or another before optical communication can be transmitted through the optical fibres. Different installation situations, different fibre termination techniques, different connector and housing designs, among other factors exist that can manage different cable element length movements.

8.2 Different termination cases

Six different termination cases for fibre optic interconnecting devices and passive components which are included in IEC 61753-1 [23] are shown in Table 3 that represent a large number of terminated cables.

NOTE In each termination case, several variants can be present in real applications. For easier representation, the parts for cable kink protection, for example boots, are not shown in the figures.

Table 3 – Overview of different termination cases

No.	Title	Figure	Recom-mended tests for evaluation of shrinkage effects	Recom-mended tests for perform-ance evaluation
1	Cable terminated with connector		9.3	Annex D
2	Cable terminated with hardened connector		9.4	Annex E
3	Cable fixed into a module and fibres terminated with connectors		9.5	Annex F
4	Cable fixed into a divider with individual fibres fed into fan-out cables and the ends terminated with connectors		9.6	Annex G
5	Cable fixed into a protective housing and fibres terminated with splices		9.7	Annex H
6	Cable fixed into a protective housing and terminated with connectors		9.8	Annex I

In this document, a separate termination case for cables terminated into passive optical components is not included because many different termination variants are used in the industry. Therefore, recommendations for suitable tests for performance valuation of such cables are not possible. Nonetheless, some information about recommended tests for performance valuation of cables for termination to a passive optical component can be taken from one of the six termination cases in Table 3 that forms the closest approximation to the real situation.

9 Recommended tests for evaluation of shrinkage effects

9.1 General

Recommended tests for the cable performance evaluation of different termination cases are given in Annex D to Annex I. In Clause 9, the recommended tests, test parameters and shrinkage limits for evaluation of shrinkage effects are given.

For connector terminations that do not involve the full cable (i.e. connectors on a 900 µm tight buffered fibre or simplex units in a breakout cable), testing the full cable is not needed. For cables terminated in closures that are spliced and have the rigid strength elements and cable sheath secured, the shrinkage test is not applicable.

9.2 Limitation of tests for determination of shrinkage effects

It is highlighted that cable shrinkage and cable expansion and contraction testing will not be able to provide complete optical performance information for terminated cables. Nevertheless, shrinkage data during and after test can provide helpful information when classifying a cable and in understanding the changes in attenuation during temperature cycle tests.

9.3 Cables terminated with connectors

9.3.1 Performance indicator tests

Recommended tests for the performance evaluation of cables to be terminated with connectors are given in Annex D. Table D.1 lists optional tests that can be used as performance indicators. This clause gives guidance to the optional tests that evaluate shrinkage effects.

9.3.2 Cable shrinkage

As described in Clauses D.2 to D.4, the acceptable cable shrinkage limit depends on the connector and cable type used as well as the real termination situation. Although a single, very low shrinkage value would be desirable for component manufacturers, most mitigate the effect of shrinkage through component design. Therefore, a few different grades are proposed to widen the range of available cables.

The sheath shrinkage testing of simplex and duplex cable samples with a nominal length of 1 m is recommended using IEC 60794-1-211 [14], method F11A. The recommended test parameters for shrinkage testing are listed in Table 4 and the recommended grades for shrinkage are 1, 2 or 3 in Table 5. Grade 4 is not recommended for connector termination. Annex C provides a template for shrinkage testing of cables.

9.3.3 Cable thermal expansion and contraction

Thermal expansion and contraction occur when changing the temperature from ambient to low or high temperature (e.g. from +23 °C to +70 °C or from +23 °C to −25 °C).

A suitable procedure to measure the length on short cable samples is described in Annex D. With this procedure, the change in length of the cable sheath and optionally the cable elements can be determined at low, high and ambient temperature.

Different thermal expansion and contraction of cable elements often results in an increase in attenuation. Measurement on cable samples has shown that cables having a larger change of length (contraction) at low temperature also typically have a larger increase in attenuation when changing from a high to a low temperature and during prolonged exposure at low temperatures (see Annex B).

9.3.4 Cable element forces

For further study.

9.4 Cables terminated with hardened connectors

9.4.1 Performance indicator tests

Recommended tests for the performance evaluation of cables to be terminated with hardened connectors are given in Annex E. Table E.1 lists optional tests that can be used as performance indicators. Subclause 9.4 gives guidance to the optional test that evaluates shrinkage effects.

9.4.2 Cable shrinkage (fibre protrusion)

The maximum possible fibre or buffered fibre change in length that the hardened connector used can compensate for without any change in the optical performance should be determined.

From this maximum change in length, the movement of the inserts during mating should be subtracted.

This calculated change in length can be used for specifying the maximum allowable fibre or buffered fibre protrusion when testing the cable in accordance with IEC 60794-1-22 [13], method F17. Subclause 6.4 describes test method F17 and shows the definition of the lengths L_1, L_2 and L_3. If the buffered fibre is guided from the cable to the insert and terminated in it, then L_3 is the relevant parameter for specifying the maximum protrusion length. Length L_3 can be calculated from the measured lengths L_2 minus L_1. In the case where fibre without a buffer is guided from the cable to the insert and terminated in it, then L_2 is the relevant parameter for specifying the maximum protrusion length.

The recommended test parameters for cable shrinkage testing are listed in Table 4 and the recommended grades for change of fibre protrusion in Table 6 and Table 7. Annex C provides a template for shrinkage testing of cables.

9.5 Cables fixed into a module and fibres terminated with connectors

9.5.1 Performance indicator tests

Recommended tests for the performance evaluation of cables fixed into a module and the fibres terminated with connectors are given in Annex F. Table F.1 lists optional tests that can be used as performance indicators. Subclause 9.5 gives guidance to the optional test that evaluates shrinkage effects.

9.5.2 Cable shrinkage (fibre protrusion)

The maximum possible fibre or buffered fibre change in length that the module used can compensate for without any change in the optical performance should be determined.

This determined change in length can be used for specifying the maximum allowable fibre or buffered fibre protrusion when testing the cable according to IEC 60794-1-22 [13], method F17. Subclause 6.4 describes test method F17 and shows the definition of the lengths L_1, L_2 and L_3. The relevant parameter for specifying the maximum change of protrusion length depends on the used cable type, such as:

– cable with fibres and no tube: ΔL_2;

– cable with buffered fibres and no tube: ΔL_3;

– cable with one multi-fibre loose tube: ΔL_1.

The recommended test parameters for cable shrinkage testing are listed in Table 4 and the recommended grades for change of fibre protrusion in Table 6 and Table 7. Annex C provides a template for shrinkage testing of cables.

9.6 Cables fixed into a divider and fan-out cables terminated with connectors

9.6.1 Performance indicator tests

Recommended tests for the performance evaluation of cables fixed into a divider and the fan-out cables terminated with connectors are given in Annex G. Table G.2 and Table G.3 list optional tests that can be used as performance indicators. Subclause 9.6 gives guidance to the optional tests that evaluate shrinkage effects.

9.6.2 General

The acceptable cable shrinkage limit depends on the connector, fan-out cable, divider and cable type used as well as the real termination situation. Moreover, beside the effects caused by shrinkage, the thermal expansion effects can be significant (see Annex B) that are not covered in 9.6. Consequently, the maximum allowable shrinkage and fibre protrusion of the cables described in 9.6 should be considered as an indicator only.

The calculation of the possible fibre or buffered fibre change in length described in 9.6 is applicable for dividers that have a free space for the fibres within the divider housings as shown in Figure G.1.

In cases that the fibre overlength cannot be compensated by bending laterally, then the described approach in 9.6 is not applicable. For example, that is the case if the divider housing is filled with a compound. In that case, the complete terminated cable assembly should be tested as recommended in G.5.1.

9.6.3 Shrinkage (fibre protrusion)

The maximum possible fibre or buffered fibre change in length that the divider used can compensate for without any change in the optical performance should be determined. This length needs to cover the change in length of fibre or buffered fibre protrusion of the cable and the shrinkage of the fan-out cable, such as:

$$\Delta L_{\text{div}} = \Delta L_{\text{fibre}} + \Delta L_{\text{cable}}$$

where

ΔL_{div} is the length the divider is able to compensate;

ΔL_{fibre} is the length of the fibre or buffered fibre protrusion of cable

ΔL_{cable} is the length of the shrinkage of the fan-out cable.

A maximum allowable change of fibre or buffered fibre protrusion that is lower than the determined length should be specified when testing the cable according to IEC 60794-1-22 [13], method F17. A practical limit for the change of protrusion cannot be given because it is a balance between the behaviour of the cable and the fan-out cable. Subclause 6.4 describes test method F17 and shows the definition of the lengths L_1, L_2 and L_3. The relevant parameter for specifying the maximum change of protrusion length depends on the used cable type, such as:

– cable with buffered fibres and no tube: ΔL_3;

– cable with loose tubes: ΔL_1.

The recommended test parameters for cable shrinkage testing are listed in Table 4 and the recommended grades for change of fibre protrusion in Table 6 and Table 7. Annex C provides a template for shrinkage testing of cables.

9.6.4 Shrinkage of fan-out cable

Based on the determined maximum possible length that the divider can compensate explained in 9.6.3, the allowable length for the shrinkage of the fan-out cable is calculated as:

$$\Delta L_{\text{shrinkage of fan-out cable}} = \Delta L_{\text{divider is able to compensate}} - \Delta L_{\text{fibre or buffered fibre protrusion of cable}}$$

Sheath shrinkage testing of simplex and duplex cable samples with a nominal length of 1 m is recommended using IEC 60794-1-211 [14], method F11A. The recommended test parameters for shrinkage testing are listed in Table 4 and the recommended grades for shrinkage are 1, 2 or 3 in Table 5. Grade 4 is not recommended for connector termination. Annex C provides a template for shrinkage testing of cables.

9.7 Cables fixed into a protective housing and terminated with splices

9.7.1 Performance indicator tests

Recommended tests for the performance evaluation of cables fixed into a protective housing and terminated with splices are given in Annex H. Table H.1 lists optional tests that can be used as a performance indicator. Subclause 9.7 gives guidance to the optional tests that evaluates shrinkage effects.

9.7.2 Cable shrinkage (fibre protrusion)

The maximum possible change in length of the fibre and the fibre tube (or buffered fibre) that the protective housing used can compensate for without any change in the optical performance should be determined.

These maximum changes in length can be used for specifying the maximum allowable fibre and fibre tube (or buffered fibre) protrusion when testing the cable according to IEC 60794-1-22 [13], method F17. Subclause 6.4 describes test method F17 and shows the definition of lengths L_1, L_2 and L_3. For specifying the maximum change of fibre protrusion from the edge of the fibre tube (or buffered fibre), length L_1 is suitable, and for the maximum change of the fibre tube (or buffered fibre) protrusion, length L_3 is suitable. Length L_3 can be calculated from the measured lengths L_2 minus L_1.

The recommended test parameters for the cable shrinkage (fibre protrusion) test and recommended fibre protrusion grades are listed in Table 4 and the recommended grades for change of fibre protrusion in Table 6 and Table 7. Annex C provides a template for shrinkage testing of cables.

9.7.3 Sheath shrinkage

Sheath shrinkage according to method F11B of IEC 60794-1-211 [14] can be used as an indicator for cable types that are generally suitable for properly terminated cable ends at protective housings. The installation technique should secure rigid strength elements and cable sheath, guide the loose tubes and fibres properly and can include external installation techniques. The test parameters should be taken from the detail cable specification. The maximum shrinkage should not exceed 7,5 mm (5 %).

9.8 Cables fixed into a protective housing and terminated with connectors

9.8.1 Performance indicator tests

Recommended tests for the performance evaluation of cables fixed into a protective housing and terminated with connectors are given in Annex I. Table I.1 list an optional test that can be used as a performance indicator. This clause gives guidance to the optional test that evaluates shrinkage effects.

9.8.2 Cable shrinkage

IEC 60794-2-22 [16] includes no shrinkage requirement for the sheath of the breakout cable. For the simplex cables within the breakout cable, the requirements of the family specification IEC 60794-2-50 [17] are applicable. Annex D recommends tests for performance evaluation of simplex or duplex cables to be terminated with connectors.

Many protective housings can manage over-length, and some changes in the length of reinforced cables or buffered fibres, in an effective way. In that case, the determination of the shrinkage of the complete cable is not necessary. However, if almost no change in length can be compensated for within the housing, then cable shrinkage of the complete cable should be considered.

The sheath shrinkage of breakout or mini-breakout cable samples with a nominal length of 1 m should be tested using IEC 60794-1-211 [14], method F11A. The recommended test parameters for cable shrinkage testing are listed in Table 4 and the recommended grades for sheath shrinkage in Table 5. Annex C provides a template for shrinkage testing of cables.

10 Recommended test parameters for shrinkage testing and shrinkage grades

10.1 General

The recommended test parameters for shrinkage testing are those from the operating service environments and performance categories defined for components given in IEC 61753-1. A suitable category should be selected according to the application. The termination cases in this document are pertinent to cable application according to IEC 61753-1 [23].

Because low shrinkage causes not necessarily poor attenuation performance of a cable and vice versa as described in 5.5.3 and the termination situation can vary remarkably as described in Clause 8, universal limits cannot be given. Details about different termination cases are given in Annex D to Annex I. Although a single, very low shrinkage value would be desirable for component manufacturers, most mitigate the effect of shrinkage through component design. Therefore, a few different grades are proposed to recognise the different termination situations and to widen the range of available cables.

The severities as well as the shrinkage grades can be included in the product specifications of optical fibres cables – IEC 60794 (all parts) – in the future where the working group deems it suitable.

10.2 Recommended test parameters for shrinkage testing

Method: According to method F11A for sheath shrinkage of a short cable sample or method F17 for fibre protrusion of a long cable sample

Sample length: 1 m for method F11A sheath shrinkage of a short cable sample; 20 m for method F17 fibre protrusion of a long cable sample

NOTE 1 Shrinkage data using method F11A with a cable sample length of 1 m was provided by participants in the study. No data for method F11A with a cable sample length of 150 mm and for F11B was provided that could be reviewed and compared. Therefore, method F11A with a cable sample length of 1 m is used because this method exits since several years as method F11 and was used in the study.

NOTE 2 The measured fibre protrusion of cable samples with a length of 20 m were often larger than with sample length of 5 m and 10 m (see Clause A.3). Therefore, a length of 20 m for evaluation of the fibre protrusion is used.

Test parameters: according to Table 4

Rate of cooling and heating: not to exceed 60 °C per hour

Table 4 – Temperature cycling severities for shrinkage testing for Methods F11A and F17

Low temperature T_{A2} °C	High temperature T_{B2} °C	Soak time t_1 h	Number of cycles	Related performance category [a] (informative)
Connectors, FMC, mechanical splices, fusion splice protectors, passive optical components and FMS [b]				
–10	+60	1	5	C
–10	+70	1	5	C^{HD}
–25	+70	1	12	OP
–25	+85	1	12	OP^{HD}
–40	+75	1	12	OP+
–40	+85	1	12	$OP+^{HD}$
–40	+70	4	12	I
–40	+85	4	12	I^{HD}
–40	+85	1	12	E
Hardened connectors and protective housings (wall outlets, boxes, ODFM, street cabinets and closures) [b]				
–40	+65	4	12	A
–40	+65	4	12	G
–40	+65	4	12	S

[a] Operating service environments and performance categories according to IEC 61753-1 [23]. A suitable category should be selected according to the application.

[b] Product types according to IEC 61753-1 [23].

10.3 Shrinkage grades for Method F11A

Table 5 provides recommended grades for specifying the cable sheath shrinkage suitable for a cable sample, nominal length 1 m.

Table 5 – Recommended sheath shrinkage grades

Grade	Sheath shrinkage mm
1	≤ 5
2	≤ 10
3	≤ 20
4	> 20 (no limit)

NOTE Sheath shrinkage grades for method F11A with 150 mm samples length are for future study.

10.4 Recommended shrinkage limit for Method F11B

The maximum sheath shrinkage should not exceed 7,5 mm.

10.5 Fibre protrusion grades for Method F17

Table 6 and Table 7 provide recommended grades for specifying the change of fibre protrusion suitable for cable sample length of 20 m.

Table 6 – Recommended change of fibre protrusion ΔL_1 grades

Grade	Change of fibre protrusion (ΔL_1) from the edge of the secondary fibre protection or fibre tube mm
1	≤ 25
2	≤ 50
3	≤ 100
4	> 100 (no limit)

Table 7 – Recommended change of fibre protrusion ΔL_2 grades

Grade	Change of fibre protrusion (ΔL_2) from the edge of the cable sheath mm
1	≤ 30
2	≤ 60
3	≤ 120
4	> 120 (no limit)

Annex A
(informative)

Test results of the cable shrinkage study

A.1 General

A correspondence group in IEC/SC86A/WG3 worked on several issues relating to cable shrinkage between 2016 and 2018. Amongst others, one issue in this study was to perform cable shrinkage tests and to collect and record the test results. Annex A shows examples of the shrinkage test results of the cable shrinkage study.

It should be noted that shrinkage tests on loose tube cables were also performed in the first phase. The results of these tests were not needed for the recommended test for performance evaluation of cables to be terminated with connectors. This was done for evaluation of a suitable procedure for test method F17 (cable shrinkage test with measurement of fibre protrusion on a long cable sample). Additionally, these results as well as the newly-developed test method F17 were used for the recommended tests for performance evaluation of cables for a few terminated cases.

Specifically important is the fact that similar and different cable types can have different shrinkage behaviours and have demonstrated different shrinkages. Therefore, the test results should be regarded only as possible values of the tested cable types.

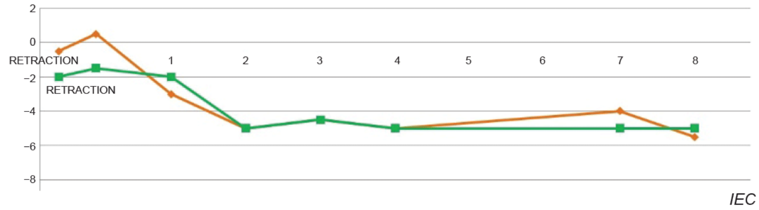
A.2 Shrinkage test results of simplex cables

A.2.1 Simplex cable types for shrinkage tests

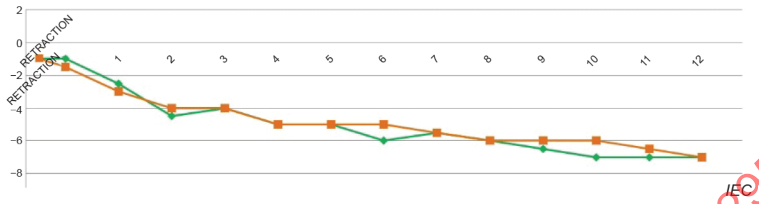
Commercially available simplex cables were tested according to IEC 60794-1-22 [13], method F11, often with a modified procedure (e.g. aging or temperature cycling from low to high temperature instead of temperature cycling from ambient to high temperature). The design of the tested simplex cables was: acrylate-coated glass fibre (125/245 µm); 900 µm secondary coating (often easy strip type); aramid yarns; flame-retardant sheath (HFFR/LSZH) between ∅1,6 mm and ∅3,0 mm.

A.2.2 Shrinkage test with different aging methods and duration

Several optical fibre cable types were tested for shrinkage according to IEC 60794-1-22 [13], method F11, including those not intended for connectorisation (and one made to deliberately show high shrinkage) in order to better evaluate the test extremes. Two samples of the different cable types were aged continuously at high temperatures and another two samples were aged using temperature cycling. The results of three cable types (no. 1, 2 and 3) are shown in Figure A.1 to Figure A.3 using green and orange lines. For sheath shrinkage (y-axis), the change of length in mm is given as a negative value. The horizontal axis values represent the number of days for continuous high temperature aging (marked with "continuous") and the number of temperature cycles for temperature cycling (marked with "cycling"). For temperature cycling, the soak time was 1 h at the high and ambient temperature.

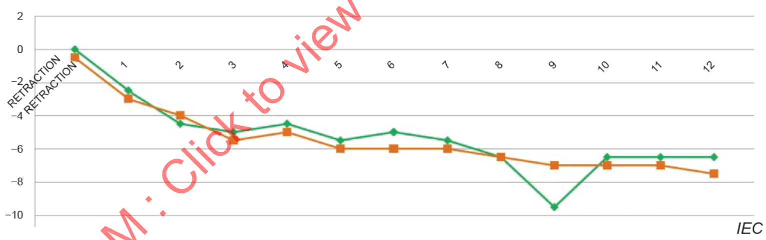


a) **Continuous at +60 °C**

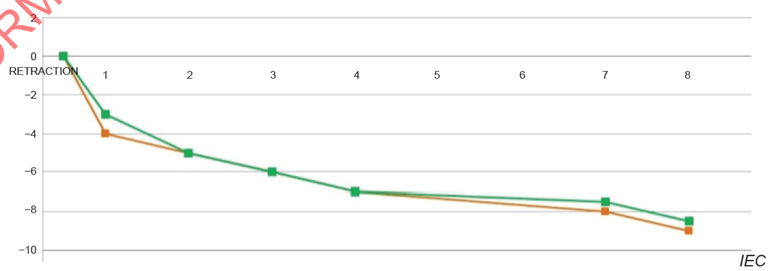


b) **Cycling with +60 °C high temperature**

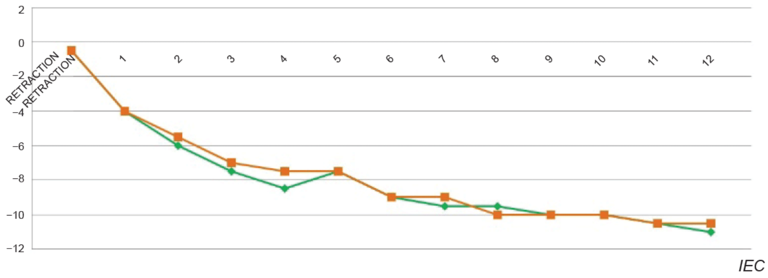
c) **Continuous at +70 °C**



d) **Cycling with +70 °C high temperature**

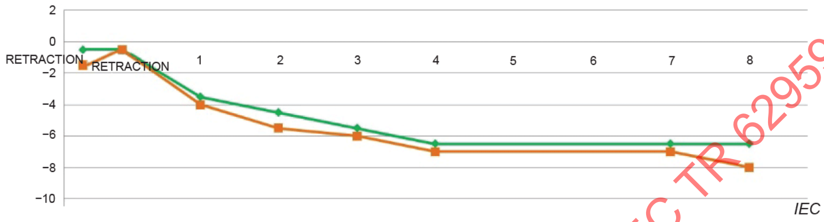


e) **Continuous at +85 °C**



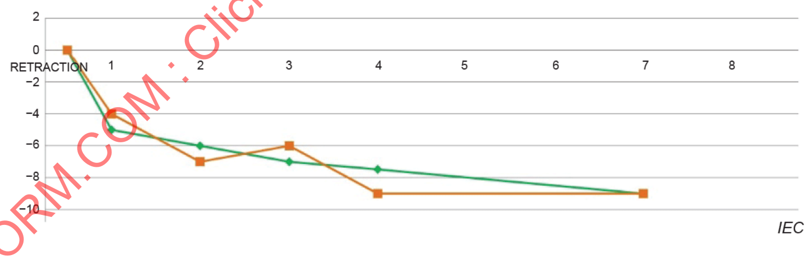
f) Cycling with +85 °C high temperature

Figure A.1 – Sheath shrinkage in mm of cable type 1 with different temperatures

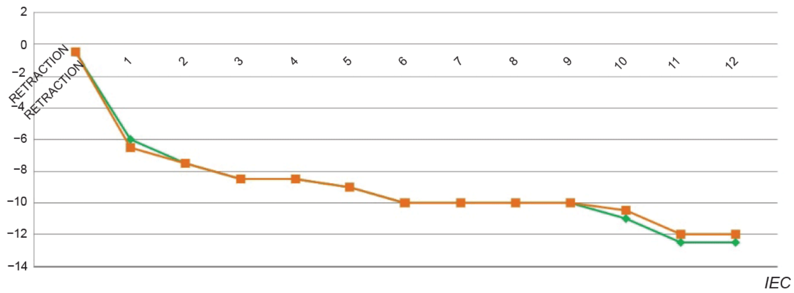


a) Continuous at +60 °C

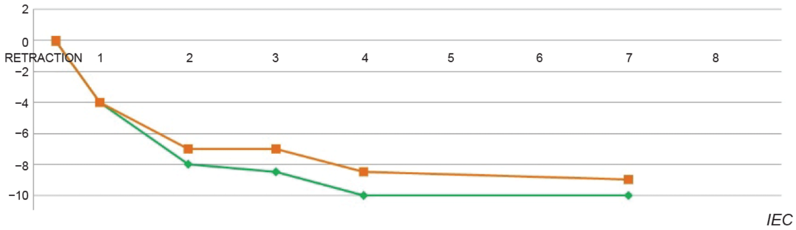
b) Cycling with +60 °C high temperature



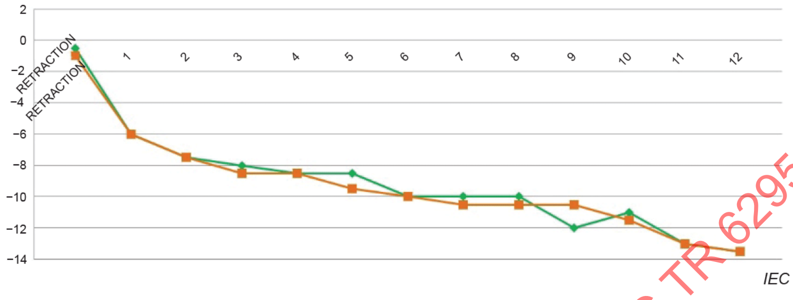
c) Continuous at +70 °C



d) Cycling with +70 °C high temperature



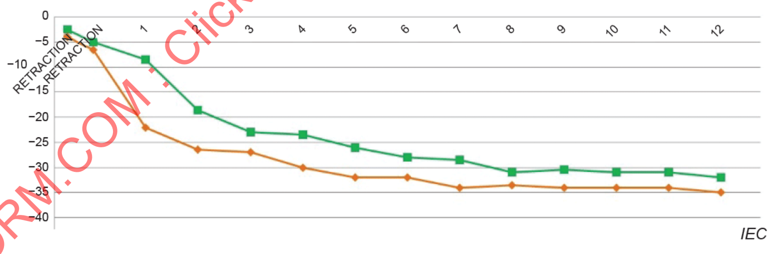
e) Continuous at +85 °C



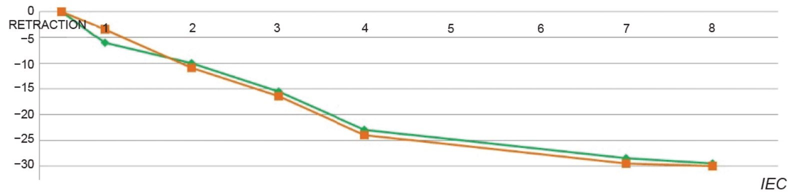
f) Cycling with +85 °C high temperature

Figure A.2 – Sheath shrinkage in mm of cable type 2 with different temperatures

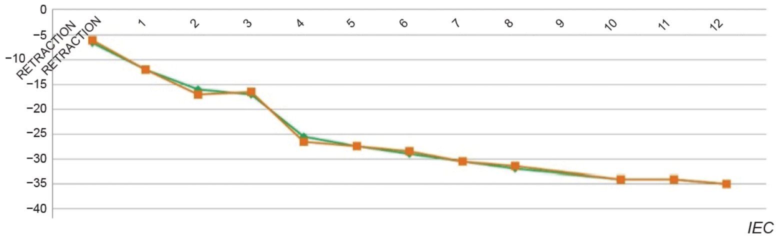
a) Continuous at +60 °C



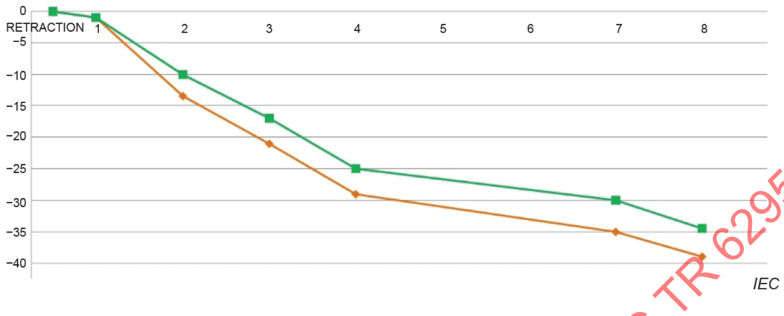
b) Cycling with +60 °C high temperature



c) Continuous at +70 °C



d) Cycling with +70 °C high temperature



e) Continuous at +85 °C

f) Cycling with +85 °C high temperature

Figure A.3 – Sheath shrinkage in mm of cable type 3 with different temperatures

Cycling between the high temperature and ambient gave slightly higher shrinkage than continuous high temperature. If there is some sort of piston effect, then maybe this would be even more pronounced if cycled between high and low temperature. Higher upper temperatures gave slightly higher shrinkage (+60 °C, +70 °C and +85 °C tested). Most of the shrinkage occurred within 2 to 4 cycles or 2 to 4 days (for continuous high temperature).

A.2.3 Shrinkage test with various numbers of temperature cycles

Shrinkage tests according to IEC 60794-1-22 [13], method F11 (modified) were performed with a simplex cable ∅2,0 mm with easy strip buffered fibre, aramid yarns and flame-retardant LSZH sheath. The simplex cable was manufactured with four different colours and afterwards the sheath shrinkage was measured.

The test parameters for the shrinkage test were: sample length 1 000 mm; temperature cycling between −25 °C/+70 °C according to IEC 60794-1-22 [13], method F1; ramp 1 °C/min.; soak time 1 h and 4 h; 8 cycles; 3 samples per colour per soak time.

Figure A.4 shows the average sheath shrinkage of all the samples of all the four different colours for the two different soak times (1 h and 4 h) separately, measured after the 2, 5 and 8 cycles. No measurement was made after 1, 3, 4, 6 and 7 cycles but the values were interpolated and included.

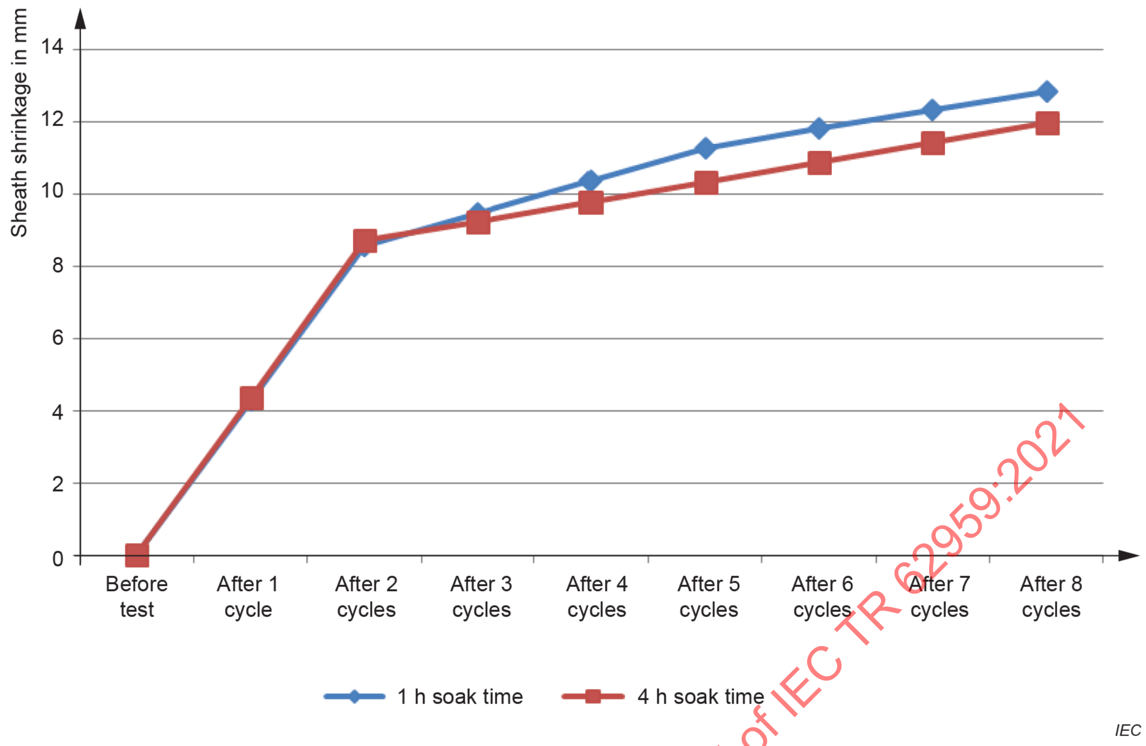


Figure A.4 – Sheath shrinkage at different number of cycles

The results show that most of the sheath shrinkage can be measured after the 2nd cycle. After more cycles, a moderate increase of the sheath shrinkage can still be observed. No significantly different sheath shrinkage values could be measured between the 1 h and 4 h soak times.

A.2.4 Shrinkage test with different sample lengths

A sheath shrinkage test according to IEC 60794-1-22 [13], method F11, was performed with a simplex cable type. The cable design was: easy strip buffered fibre; aramid yarns; LSZH sheath ∅2,0 mm.

The test parameters for the shrinkage test using method F11 were: sample length 1,0 m and 3,0 m; exposure temperature +70 °C; soak time 8 h; 5 cycles; 5 samples.

The mean sheath shrinkage after temperature cycling was calculated and is shown in Table A.1.

Table A.1 – Overview of shrinkage results

Cable sample length m	Mean sheath shrinkage mm	Mean sheath shrinkage %
1,0	14	1,4
3,0	19	0,63

The shrinkage is not linear with respect to the cable length.

A.2.5 Shrinkage test versus optical performance of two different simplex cables

Temperature cycling with change in attenuation according to IEC 60794-1-22 [13], method F12, and shrinkage tests according to IEC 60794-1-22, method F11, were performed with two different simplex cable types:

– cable type 1: single-mode glass fibre ITU-T G.657.A1 [8]; simplex ∅1,6 mm; easy strip buffered fibre; aramid yarns; LSZH sheath;
– cable type 2: single-mode glass fibre ITU-T G.657.A1 [8]; simplex ∅2,0 mm; easy strip buffered fibre; aramid yarns; LSZH sheath

Figure A.5 shows the change in attenuation during and after temperature cycling at 1 550 nm using method F12 (modified). The test parameters for temperature cycling using method F12 were: sample length 10 m; soak time 1 h; 4 cycles; $T_{A1/2/3}$ −10°C /−25°C /−40 °C; T_{B2} +70 °C.

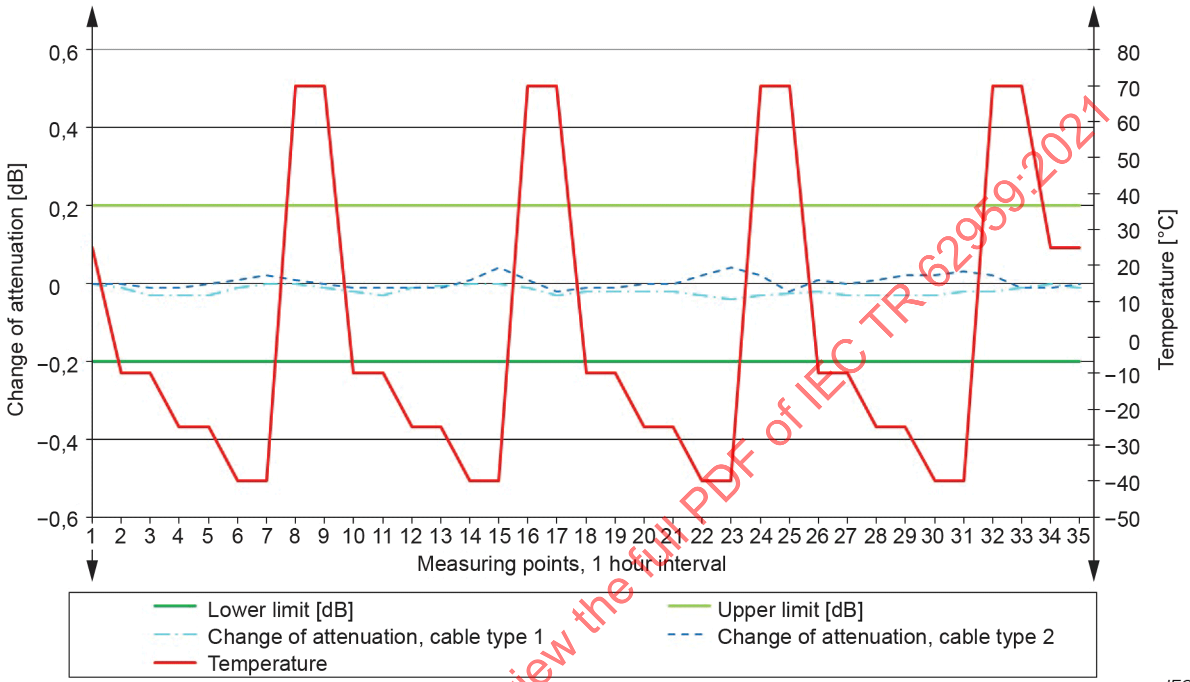


Figure A.5 – Change in attenuation during temperature cycling

The maximum change in attenuation during temperature cycling was 0,04 dB for cable type 1 and 0,04 dB for cable type 2 and afterwards 0,01 dB and 0,00 dB respectively at 1 550 nm.

As a second test, shrinkage was measured with the same two cable types using method F11. The test parameters for temperature cycling using method F12 were: sample length 1,0 m; exposure temperature +70 °C; soak time 1 h; 4 cycles; 5 samples per cable type.

The maximum sheath shrinkage after temperature cycling was 5 mm for cable type 1 and 10 mm for cable type 2.

Although the two cable types had different sheath shrinkage values, the change of optical performance is the same, as shown in Table A.2.

Table A.2 – Overview of simplex results

Cable type	Maximum sheath shrinkage	Maximum change in attenuation during temperature cycling at 1 550 nm
1	5 mm	0,04 dB
2	10 mm	0,04 dB

A.2.6 Shrinkage test versus optical performance of different versions of a simplex cable

Temperature cycling with change in attenuation according to IEC 60794-1-22 [13], method F12 and shrinkage tests according to IEC 60794-1-22, method F11 (modified), were performed with a simplex cable consisting of one single-mode glass fibre ITU-T G.652.D [9], easy strip buffer 900 µm for fibre, aramid yarns and flame-retardant LSZH sheath ∅2,0 mm. The simplex cable was manufactured with four different colours and afterwards the sheath shrinkage and the change in attenuation during temperature cycling was measured.

The test parameters for the shrinkage test were: sample length 1 000 mm; temperature cycling between −25 °C and +70 °C according to IEC 60794-1-22 [13], Method F1; ramp 1 °C/min.; soak time 1 h; 5 cycles; 3 samples per colour.

The test parameters for temperature cycling using IEC 60794-1-22 [13], Method F12 were: sample length 10 m; soak time 1 h; 5 cycles −10 °C/+70 °C followed by 5 cycles −20 °C/+70 °C; 3 samples per colour.

Figure A.6 shows the sheath shrinkage and the maximum change in attenuation at 1 550 nm during temperature cycling (−20 °C/+70 °C) of the four different colours.

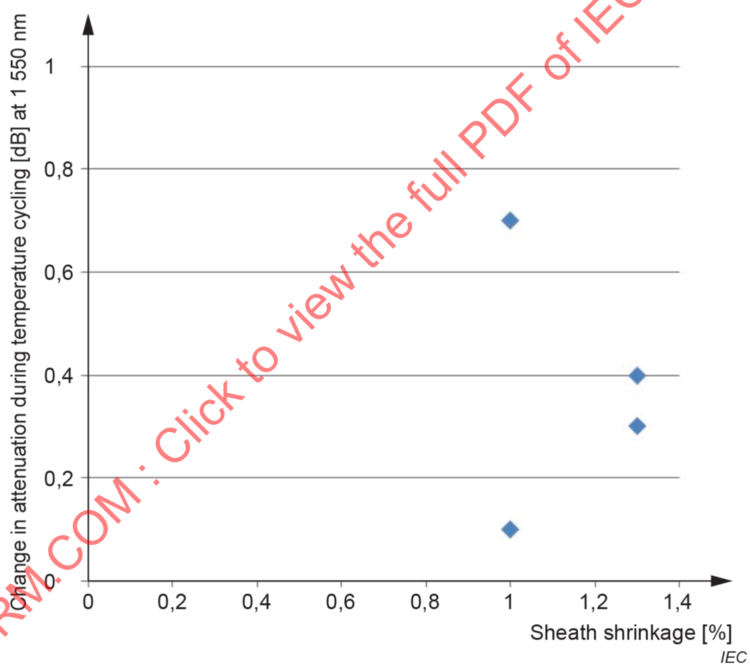


Figure A.6 – Change in attenuation versus sheath shrinkage

A correlation between the shrinkage values and the change in attenuation cannot be made, although it is the same cable type, construction, and materials (except colour batch for the sheath). This could be because the shrinkage values were very relatively close and the change of attenuation was influenced by other factors.

A.2.7 Change in length during and after climatic exposure

A test method for the change in length during climatic exposure, with results from two different cables, is shown in Annex B.

A.3 Shrinkage test results for loose tube cables

A.3.1 Loose tube cable types for shrinkage tests

Commercially available loose tube cables were tested according to IEC 60794-1-22 [13], method F17. The design of the tested loose tube cables was: acrylate-coated glass optical fibres (125/245 µm); dry and jelly-filled unitube or stranded loose tubes; aramid yarn or glass-roving strength members; flame-retardant (HFFR/LSZH) or PE sheath. The stranded loose tube cables contained a central strength member. The change in the protrusion lengths of different cable elements was measured to get comprehensive information on the behaviour of the tested cables.

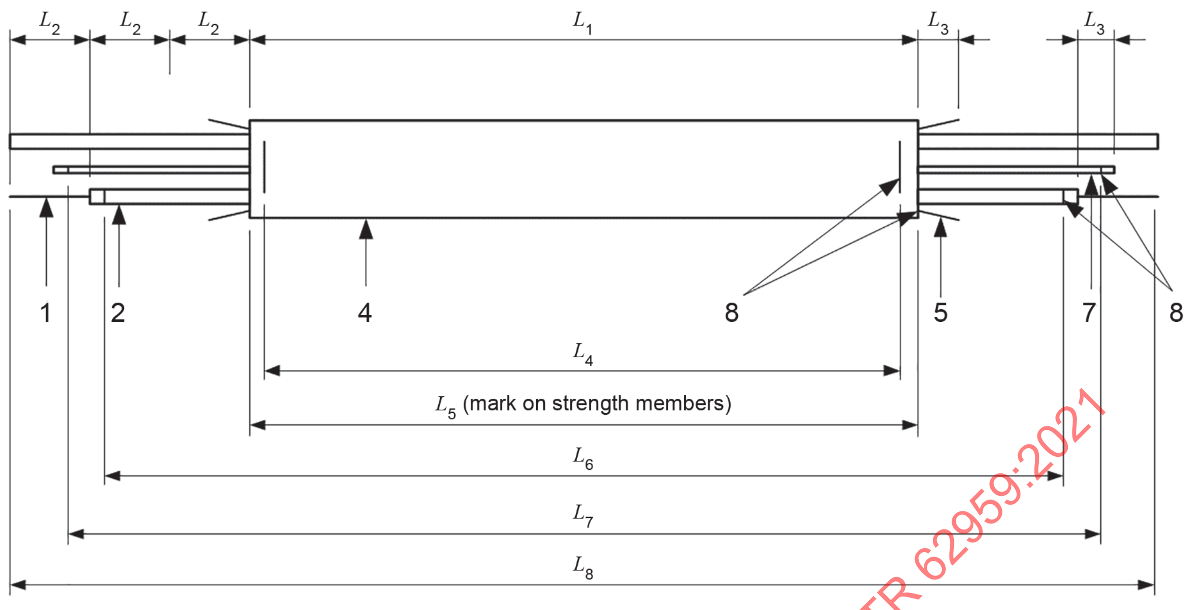
A.3.2 Shrinkage test (method F11 modified) of four loose tube cable types

Cable shrinkage tests similar to IEC 60794-1-22 [13], method F11 (modified) were performed with four different multi-fibre loose tube cable types, as described in Table A.3 and labelled as type 1 to 4.

Table A.3 – Details of loose tube cable types

Cable type	Cable design			
	Construction	Filling of loose tube(s)	Strength members	Sheath material
1	Unitube	Dry	Glass yarns	Flame-retardant LSZH
2	Unitube	Jelly-filled	Glass yarns	Flame-retardant LSZH
3	Stranded	Dry	Glass yarns	Flame-retardant LSZH
4	Stranded	Jelly-filled	Glass yarns	HDPE

The preparation of samples, the measured cable element types and the measured lengths were modified from method F11, as Figure A.7 shows.



L_1	L_2	L_3	L_4	L_6	L_7	L_8
1 020 ±5	30 ±3	15 ±3	1 100 ±1	1 120 ±1	1 150 ±1	(1 200)

Key

1 bundle of fibres

2 loose tube

4 outer cable sheath

5 outer strength member

7 central strength member

8 mark

Figure A.7 – Preparation of sample and measured lengths

The test parameters were: soak time 1 h; 8 cycles; maximum specified temperature of cable T_{A2} − 40 °C and T_{B2} + 70 °C; 1 °C/min; 2 samples per cable type; measurement of cable element lengths after 4, 6 and 8 cycles at ambient temperature.

After temperature cycling according to IEC 60794-1-22 [13], method F1, practically no change in the length of the central strength members (L_7) and the length of the fibres (L_8) could be measured. The small changes were within the measurement uncertainty of ±1 mm.

Figure A.8 shows the sheath (L_4) and loose tube (L_6) shrinkage as the average of the two samples for each cable type, measured after 4, 6 and 8 cycles.

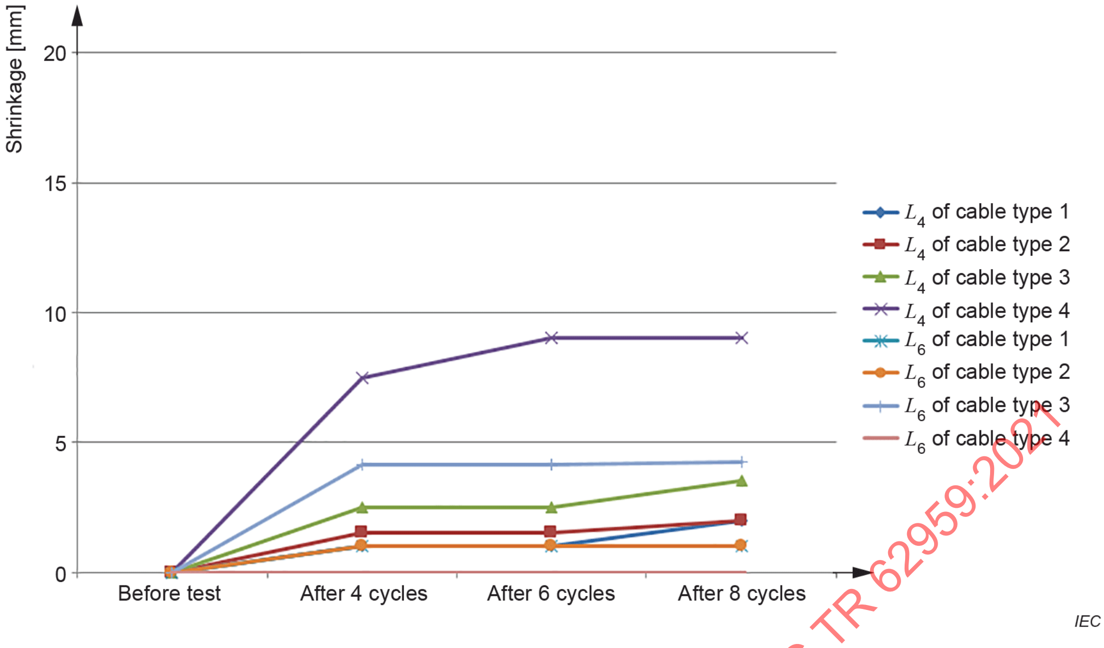


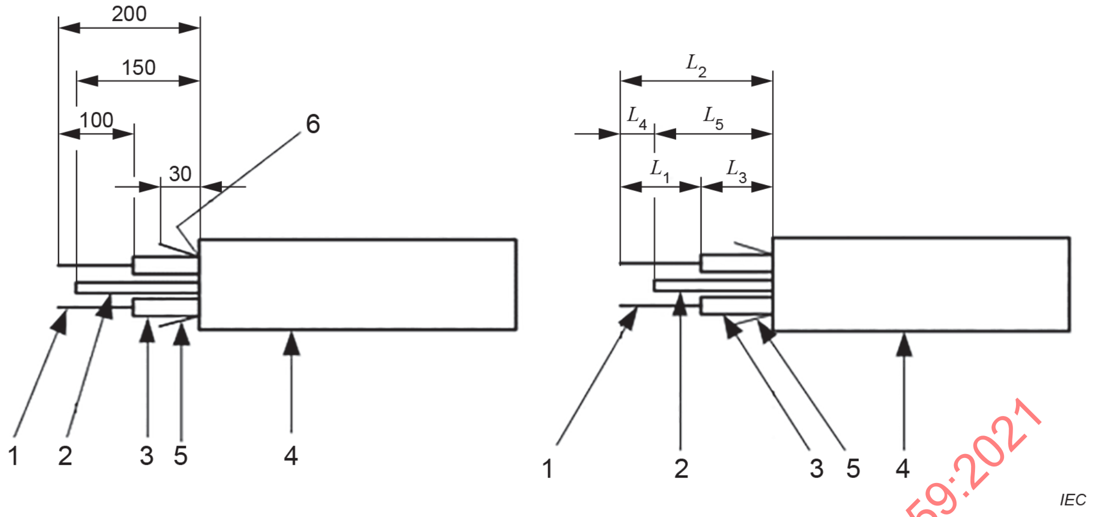
Figure A.8 – Shrinkage of sheath and loose tube after different number of cycles

The sheath shrinkage (L_4) of cable type 4 (stranded loose tube cable with HDPE sheath) showed the highest value of 9 mm compared to the other cables type with values between 2 mm and 3,5 mm (after 8 cycles).

A.3.3 Shrinkage test (method F17) of four loose tube cable types

Cable shrinkage tests according to IEC 60794-1-22 [13], method F17 (modified), were performed with three different lengths (5 m, 10 m and 20 m) and four different multi-fibre loose tube cable types. The four loose tube cable types were the same as in A.3.2.

The preparation of samples and the measured or calculated protrusion lengths were conducted using a modified version of method F17 as included in IEC 60794-1-22 [13], as shown in Figure A.9.



Key

1 bundle of fibres

2 central strength member

3 loose tube

4 outer cable sheath

5 outer strength members

6 mark

Figure A.9 – Preparation of sample and measured or calculated protrusion lengths

The test parameters were: soak time 2 h; 12 cycles; maximum specified temperature of cable T_{A2} − 40 °C and T_{B2} + 70 °C; 1 °C/min; cable coils of 0,30 m to 0,35 m in radius in chamber; measurement of fibre and cable element protrusion after 4, 8 and 12 cycles at ambient temperature.

The measurement uncertainty was approximately ±1 mm per measured length.

The mean protrusion values were calculated from the measured fibre, loose tube and central strength member protrusion lengths on both ends. Those mean protrusion lengths are shown in Figure A.10 to Figure A.13 for each cable type separately.

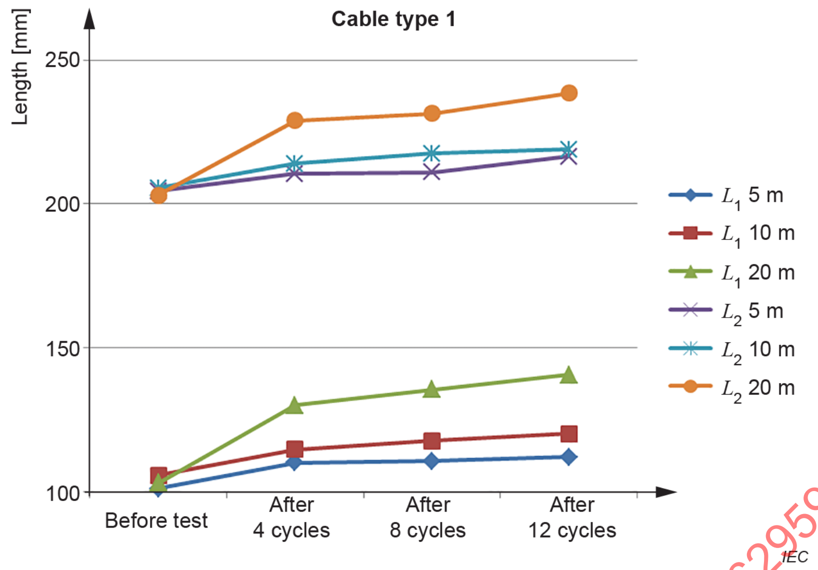


Figure A.10 – Protrusion length of cable type 1

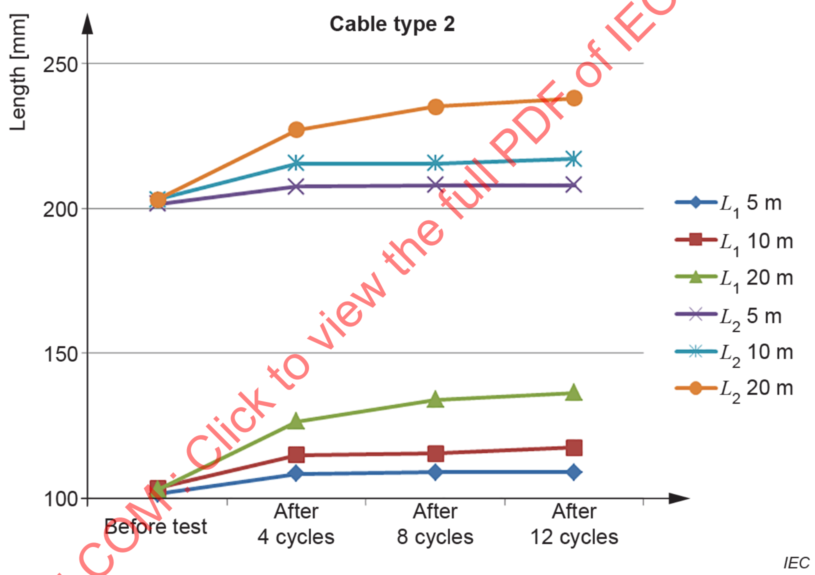


Figure A.11 – Protrusion length of cable type 2

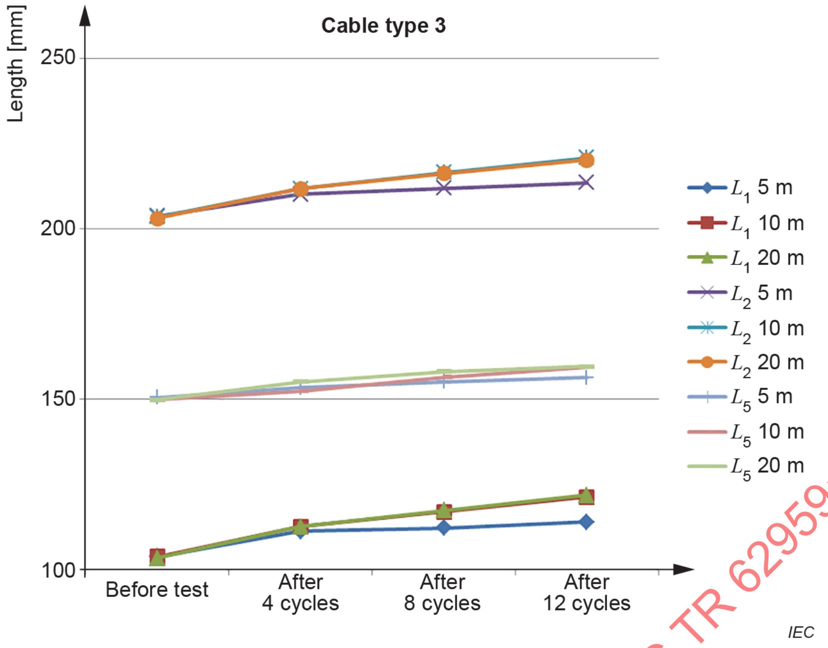


Figure A.12 – Protrusion length of cable type 3

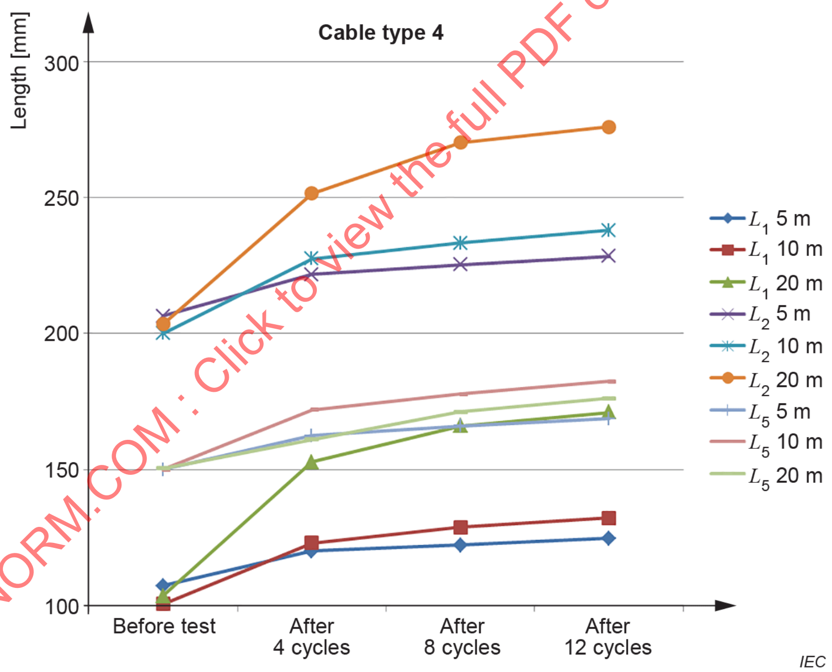


Figure A.13 – Protrusion length of cable type 4

The results regarding different sample lengths show that the fibre (L_1, L_2) and central strength member (L_5) protrusion lengths have increased with the length of the cable sample, except for cable type 3 where no real difference in the protrusion lengths between the sample lengths of 10 m and 20 m could be observed.

The results regarding different number of cycles show that the fibre, loose tube and central strength member protrusion has increased significantly during the first 4 cycles but afterwards the increase gradually reduced.

The change in protrusion of the loose tubes (L_3) was low, approximately 0 mm for cable types 1, 2 and 3 and 5 mm for cable type 4 at each end of the 20 m sample length and after 12 cycles.

The change in protrusion of the central strength member (L_5) was moderate, approximately 10 mm for cable type 3 and 26 mm for cable type 4 at each end of the sample length of 20 m and after 12 cycles.

A.3.4 Shrinkage test of nine unitube cable types

Cable shrinkage tests according to IEC 60794-1-22 [13], method F17, were performed with nine different multi-fibre unitube cable types described in Table A.4 and labelled as type A to I. They contained a central jelly-filled loose tube ∅3,4 mm with a number of single-mode fibres according to ITU-T G.657.A1 [8] and were all manufactured by the same cable manufacturer.

Table A.4 – Details of unitube cable types

Cable type	Fibre count	Strength members	Sheath material	Cable diameter mm	Sheath thickness mm	Extrusion method	Factory location	Remarks
A	12	E-glass, 12 yarns	HFFR type 1 – batch A	7,0	1,2	Tube	Europe	
B	12	E-glass, 12 yarns	HFFR type 1 – batch B	7,0	1,2	Tube	Europe	
C	12	E-glass, 12 yarns	HFFR type 2 – batch A	7,0	1,2	Tube	Asia	
D	12	E-glass, 12 yarns	HFFR type 2 – batch B	7,0	1,2	Tube	Asia	
E	12	E-glass, 12 yarns	HFFR type 2 – batch C	7,0	1,2	Tube	Asia	
F	12	E-glass, 12 yarns	LLDPE type 1 – batch A	6,8	1,1	Pressure	Asia	Cable drum 1
G	12	E-glass, 12 yarns	LLDPE type 1 – batch A	6,8	1,1	Pressure	Asia	Cable drum 2
H	4	E-glass, 24 yarns	LLDPE type 1 – batch A	7,7	1,1	Pressure	Asia	
I	6	Aramid, 18 yarns	LLDPE type 1 – batch B	6,5	1,3	Tube	Europe	

The test parameters were: sample length 10 m; soak time 1 h; 4 cycles; maximum specified temperature of cable T_{A2} −30 °C and T_{B2} +70 °C; 1 °C/min; measurement of fibre protrusion after 1, 2 and 4 cycles at ambient temperature. No measurement was made after 3 cycles, but the values were interpolated and included. The mean values of the change of protrusion were calculated from the measured fibre and unitube protrusion lengths on each end of two samples. Those mean change of protrusion lengths are shown in Figure A.14 for each cable type.

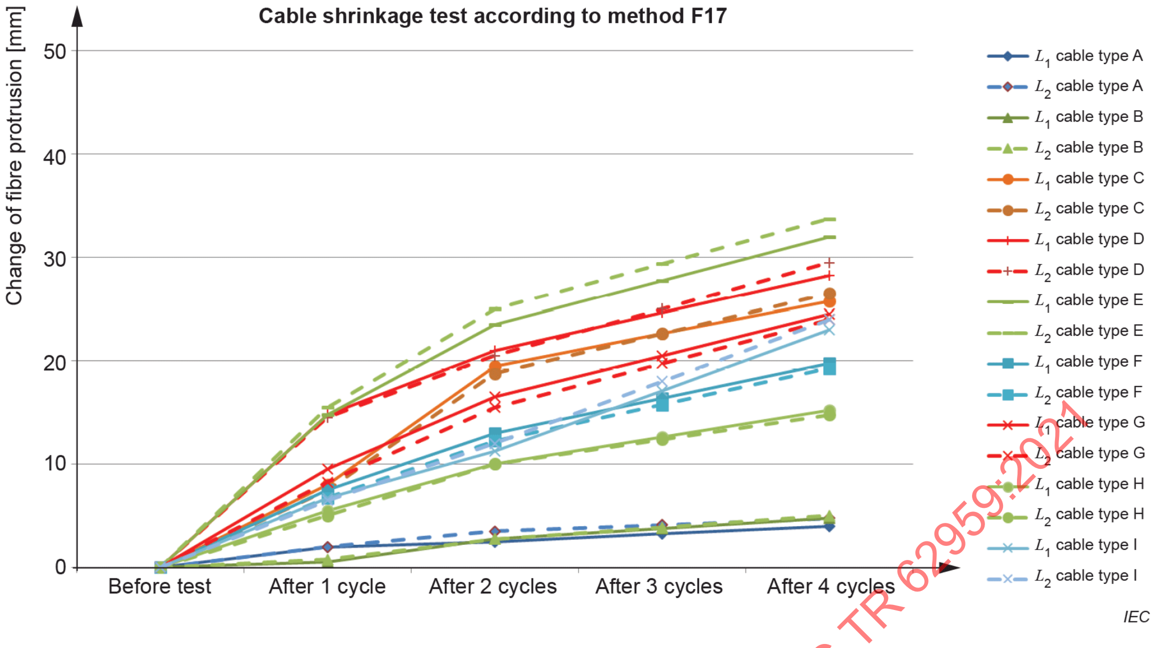


Figure A.14 – Change of fibre protrusion

The results show that the change of fibre protrusion values (L_1 and L_2) vary significantly between the different cable types. Larger change of fibre protrusion could be measured after 4 cycles compared to after 1 and 2 cycles. The change in protrusion of the tubes ($L_3 = L_2 - L_1$) were very small and within the measurement uncertainty of ±1 mm.

Annex B
(informative)

Test method for change in length during climatic exposure

B.1 General

The purpose of this test method is the finding of correlations between the change of length of cables and the change in attenuation observed during a climatic test.

According to IEC 60794-1-22 [13], method F11, sheath shrinkage (cables intended for patch cords), sheath length is measured at room temperature before and after temperature cycling on samples with a length of 1 m.

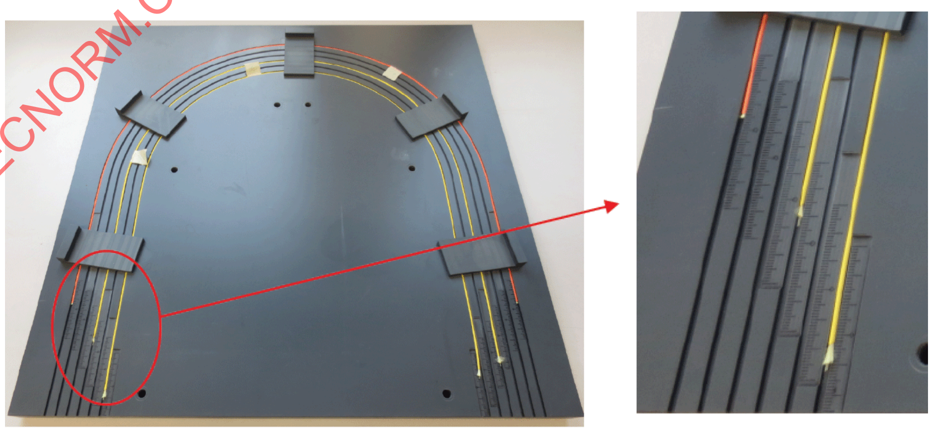
The method described in Annex B allows the change in length of cables during the climatic test in the chamber to be measured. This can yield valuable information on the behaviour of the cable types in the cold and hot phases of the test.

B.2 Cable samples

Two different simplex cable types (with orange and yellow cable sheath and named as such) were tested each having an outer cable diameter of 2,0 mm. They both contained a single-mode fibre (ITU-T G.657.A2 [8]) in a 900 µm loose secondary coating with aramid yarns between the secondary coating and the LSZH cable sheath.

B.3 Apparatus for determination of the change in length

A special plate with grooves was manufactured holding up to six thin cable samples with a length of 1 m held laterally, but friction-free movement is possible in the longitudinal direction for cables with an outer diameter ≤ 3 mm, as shown in Figure B.1. It was carefully considered that the samples can move freely in the longitudinal direction as a compromise to easily measure the change in length during temperature exposure. A possible measurement inaccuracy due to a minimal friction is smaller than the reading precision of the scale for determination of the length.



IEC

Figure B.1 – Apparatus for holding cable samples

B.4 Procedure for determination of the change in length

The cable samples were climatically exposed according to IEC 61300-2-22 [22] with the following parameters.

Temperature:	−25 °C to +70 °C ± 2 °C as defined for category OP in IEC 61753-1 [23]
Duration at extremes:	60 min
Number of cycles:	12
Rate of change:	1 °C/min
Initial sample length:	1 000 mm of sheath

The final sheath length of each sample was measured at both extreme temperatures in the last cycle (maximum contraction and shrinkage). The points where the measurements were made are shown in Figure B.2.

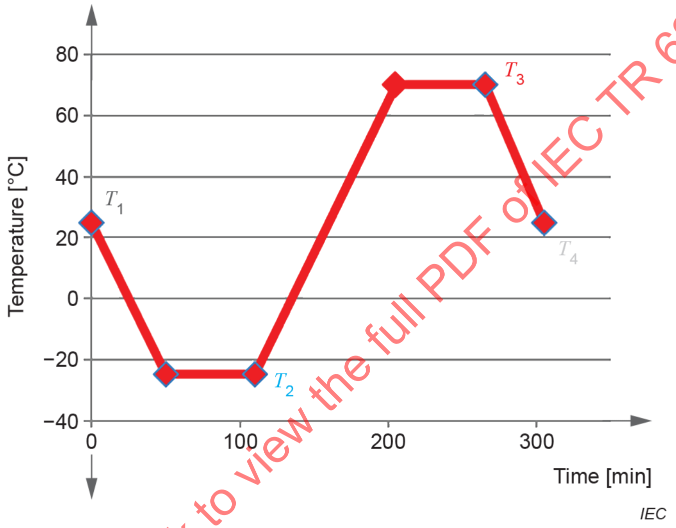


Figure B.2 – Temperature cycle with measurement points

B.5 Test results for the change in length

The length of the cable sheath during climatic testing was measured for both cable types, as given in Figure B.3. The initial lengths at T_1 were measured before temperature cycling. The lengths at T_2 and T_3 were measured at the extremes in the 12th cycle. The lengths at T_4 were measured after temperature cycling.

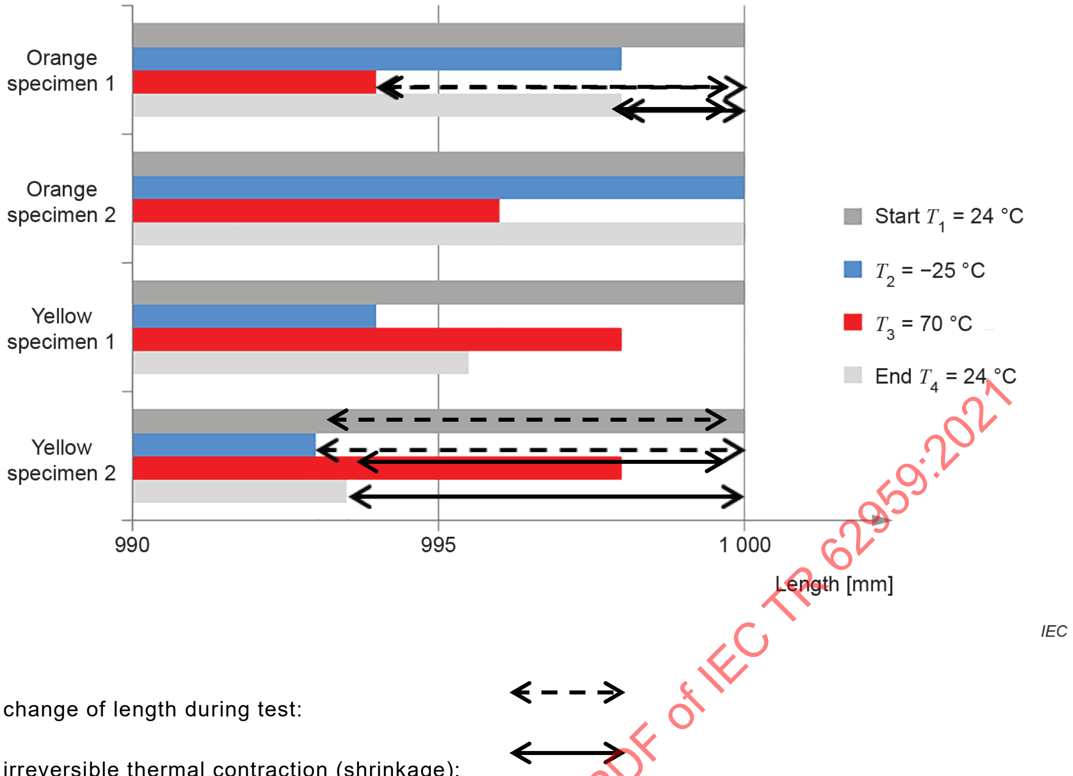


Figure B.3 – Cable sheath length measurement results

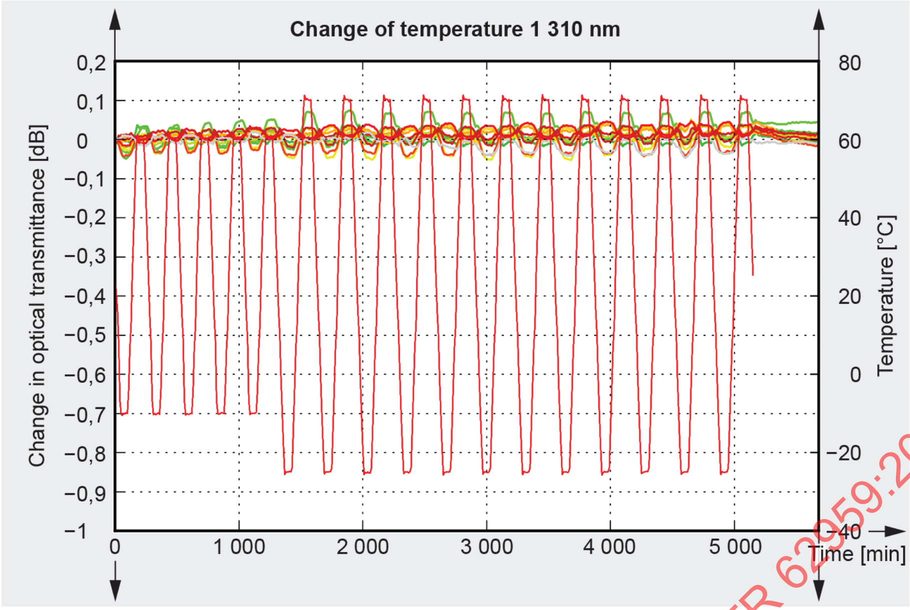
B.6 Procedure for determination of the change in attenuation

Both cable types were connectorised for the change of temperature with monitoring of the change in attenuation test.

Number of DUTs:	12
Connector type:	SC plugs
Cable length:	3 m
Test procedure:	IEC 61300-2-22 [22]
Temperatures and number of cycles:	−10 °C to +60 °C ± 2 °C as defined for category C in IEC 61753-1 [23], 5 cycles −25 °C to +70 °C ± 2 °C as defined for category OP in IEC 61753-1, 12 cycles
Duration at extremes:	60 min
Rate of change:	1 °C/min
Humidity:	uncontrolled
Location of DUT:	complete DUT with 3 m cable and two connections (SC plug – SC adaptor – SC plug on each side) inside the chamber. Short ends of the measurement cables for connection to the attenuation measuring equipment were also inside the chamber.
Wavelengths:	1 310 nm/1 550 nm/1 625 nm

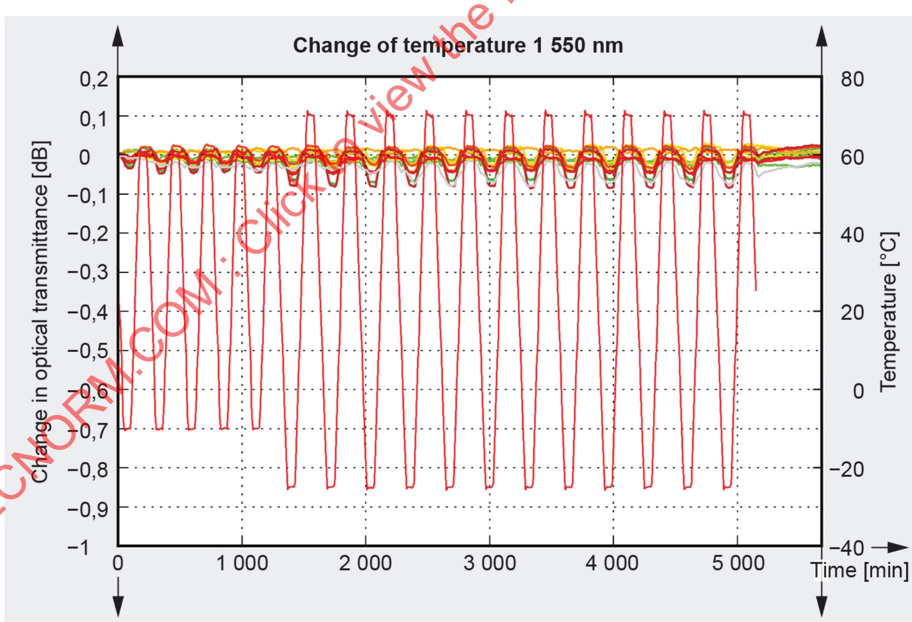
B.7 Test results for the change in attenuation

Figure B.4 to Figure B.9 give the measured changes in optical transmittance and the maximum change in attenuation of all DUTs at three wavelengths for each DUT.



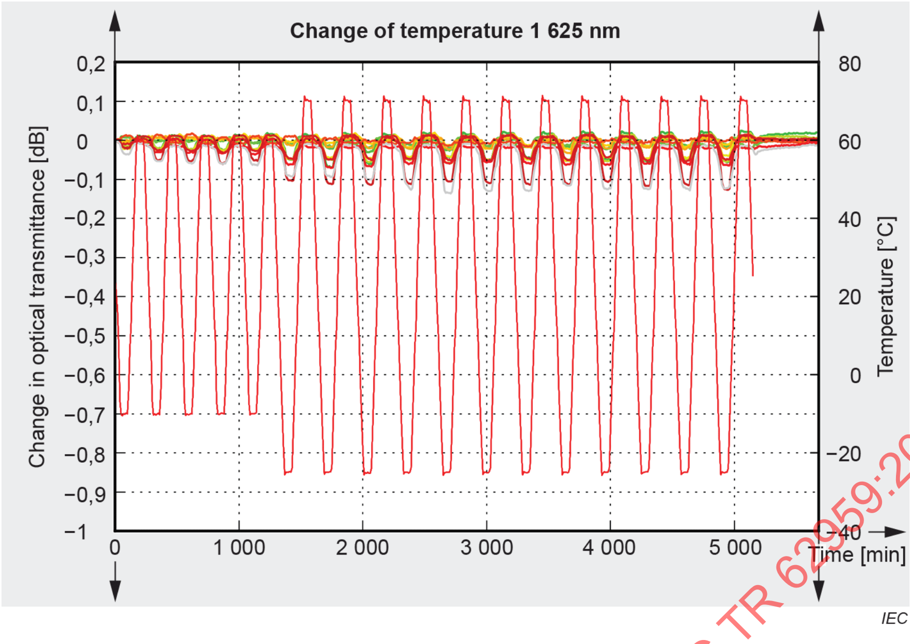
1 310 nm	Ch13	Ch14	Ch15	Ch16	Ch17	Ch18	Ch19	Ch20	Ch21	Ch22	Ch23	Ch24
max. change in attenuation [dB]	0,03	0,09	0,11	0,05	0,09	0,06	0,05	0,07	0,06	0,05	0,06	0,07

Figure B.4 – Change in attenuation of orange cable samples at 1 310 nm



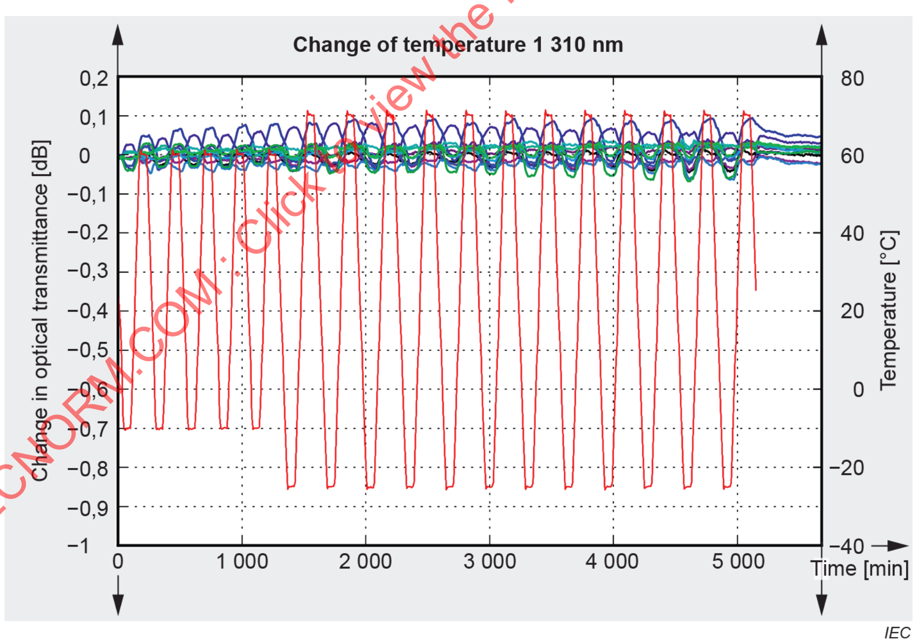
1 550 nm	Ch13	Ch14	Ch15	Ch16	Ch17	Ch18	Ch19	Ch20	Ch21	Ch22	Ch23	Ch24
max. change in attenuation [dB]	0,1	0,04	0,04	0,06	0,04	0,06	0,02	0,06	0,05	0,06	0,11	0,08

Figure B.5 – Change in attenuation of orange cable samples at 1 550 nm



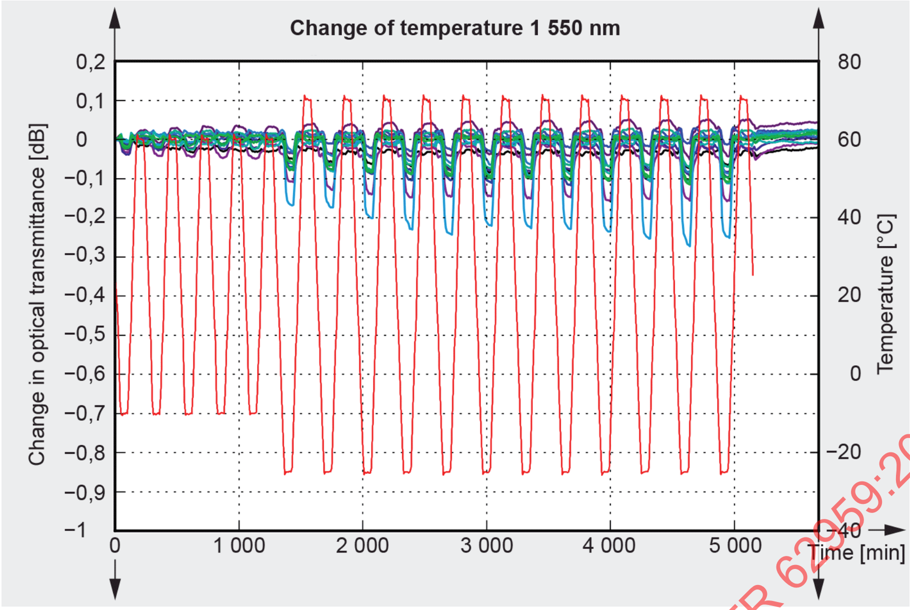
1 625 nm	Ch13	Ch14	Ch15	Ch16	Ch17	Ch18	Ch19	Ch20	Ch21	Ch22	Ch23	Ch24
max. change in attenuation [dB]	0,09	0,04	0,03	0,08	0,06	0,04	0,05	0,03	0,07	0,07	0,14	0,14

Figure B.6 – Change in attenuation of orange cable samples at 1 625 nm



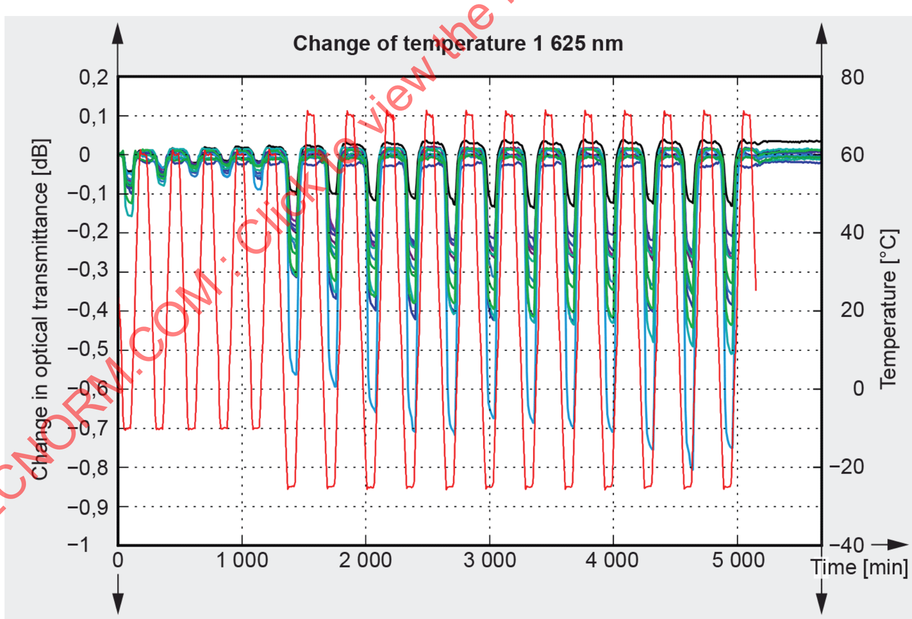
1 310 nm	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10	Ch11	Ch12
max. change in attenuation [dB]	0,07	0,05	0,05	0,09	0,14	0,06	0,07	0,05	0,05	0,04	0,1	0,05

Figure B.7 – Change in attenuation of yellow cable samples at 1 310 nm



1 550 nm	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10	Ch11	Ch12
max. change in attenuation [dB]	0,09	0,1	0,16	0,11	0,14	0,07	0,11	0,3	0,13	0,1	0,13	0,13

Figure B.8 – Change in attenuation of yellow cable samples at 1 550 nm



1 625 nm	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10	Ch11	Ch12
max. change in attenuation [dB]	0,18	0,31	0,27	0,26	0,43	0,27	0,36	0,82	0,53	0,28	0,37	0,46

Figure B.9 – Change in attenuation of yellow cable samples at 1 625 nm

B.8 Comparison of change in length with change in attenuation

Table B.1 compares results selected from change in length and change in attenuation testing.

Table B.1 – Comparison of change in length with change in attenuation

Cable type	Orange	Yellow	Data from
Maximum change of length at −25 °C (T_2) [mm]	2	7	Distance of end of blue bar to 1 000 mm in Figure B.3
Maximum change of length after cycling at +24 °C (T_4) [mm]	2	6,5	Figure B.3, marked with ⟷
Maximum change in attenuation [a] at −25 °C at 1 310 nm [dB]	0,11	0,14	Figure B.4 and Figure B.7
Maximum change in attenuation [a] at −25 °C at 1 550 nm [dB]	0,11	0,30	Figure B.5 and Figure B.8
Maximum change in attenuation [a] at −25 °C at 1 625 nm [dB]	0,14	0,82	Figure B.6 and Figure B.9

[a] Peak-to-peak

B.9 Conclusion

The comparison in Table B.1 shows the higher the change of length at −25 °C (T_2) and the change of length (shrinkage) at end of cycling (T_4) at room temperature, the higher the increase in attenuation during temperature cycling.

Cables that show higher reversible length reduction during the cold phase have a higher increase in attenuation during this phase. Differences are clearly visible at 1 625 nm.

Irreversible thermal contraction (shrinkage) measured before and after temperature cycling testing at room temperature is important, but the additional change in length during temperature cycles can cause higher attenuation during the cold phase. Both cables show low attenuation at the end of the test although the irreversible shrinkage is much higher for the yellow cable. So, the reversible change of length is important information.

Measurement of this reversible shrinkage during the cold and hot phases can be helpful when classifying a cable and to understand the high attenuations observed during the change of temperature test.

Annex C
(informative)

Shrinkage testing template

The template in Table C.1 can be used for specifying the shrinkage testing of cables.

Table C.1 – Shrinkage testing template

Type of shrinkage method	**Shrinkage on a short cable sample**	**Fibre protrusion on a long cable sample**
Cable element under consideration	Cable sheath	Fibre protrusion from the edge of the secondary fibre protection or fibre tube and from the edge of cable sheath
Test method	IEC 60794-1-211 F11A [14]	IEC 60794-1-22 F17 [13]
Test sample length	1 m	20 m
Low and high temperature for temperature cycling	Low and high temperature in °C: −10 / +60 −10 / +70 −25 / +70 −25 / +85 −40 / +75 −40 / +85 −40 / +70 −40 / +65	Related performance category [a] (informative): C C^{HD} OP OP^{HD} OP+ $OP+^{HD}$, I^{HD}, E I A, G, S
Requirement(s)	Sheath shrinkage: Grade 1: ≤ 5 mm Grade 2: ≤ 10 mm Grade 3: ≤ 20 mm Grade 4: > 20 mm	Change of fibre protrusion (ΔL_1) from the edge of the secondary fibre protection or fibre tube: Grade 1: ≤ 25 mm Grade 2: ≤ 50 mm Grade 3: ≤ 100 mm Grade 4: > 100 mm Change of fibre protrusion (ΔL_2) from the edge of cable sheath: Grade 1: ≤ 30 mm Grade 2: ≤ 60 mm Grade 3: ≤ 120 mm Grade 4: > 120 mm

[a] Operating service environments and performance categories according to IEC 61753-1 [23]. A suitable category should be selected according to the application.

Annex D
(informative)

Recommended tests for performance evaluation of cables to be terminated with connectors

D.1 General

Annex D describes termination case no. 1 listed in 8.2 where connectors are directly terminated onto simplex or duplex cable ends. Figure D.1 shows a cable terminated to a connector plug.

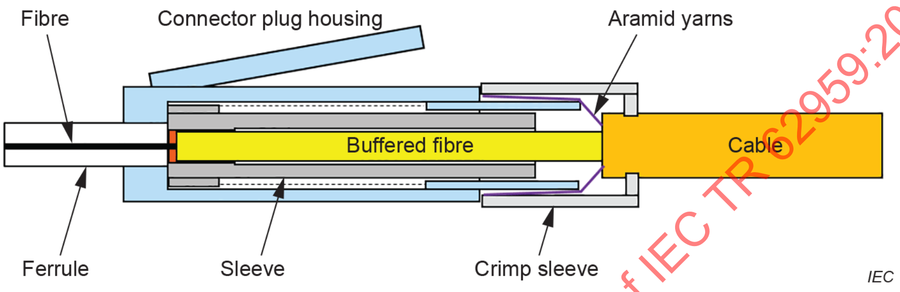


Figure D.1 – Cable terminated with connector plug

Connectors used are for an indoor controlled or outdoor protected environment (see IEC 61753-1 [23]) and are described in more detail in Clause D.2.

Connector types with sealing features, called hardened connectors or harsh environment connectors, are not considered in Annex D. See Annex E.

D.2 Connector types and design

Many connector types exist for indoor controlled and outdoor protected environments, terminated onto simplex or duplex cables. Typical types are, but not exclusively, SC, FC, LSH and LC that are specified in the IEC 61754 [26] connector series. Each connector type, for example the LC shown in Figure D.2, can have at least two design variants with different methods for termination onto the cable.

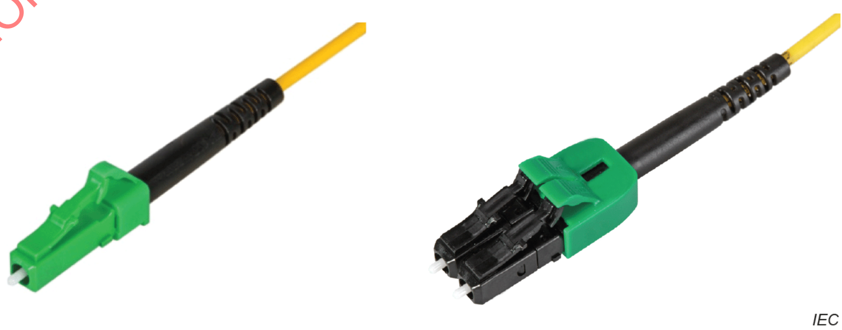


Figure D.2 – LC connector variants

Connectors in IEC 61754 (all parts) [26] have specified dimensions that are relevant for mating to an adapter (or socket) of the same type. The cable fixing method is not standardised, and every manufacturer can design it to their own requirements.

Generally, the connectors are designed for a few similar cable types or a certain cable type. Ideally, all fixing points of all the cable elements are located in one place so that no buckling can occur. In reality, the fixing points are staggered to enable a compact connector design and an easy termination process (see Figure D.3).

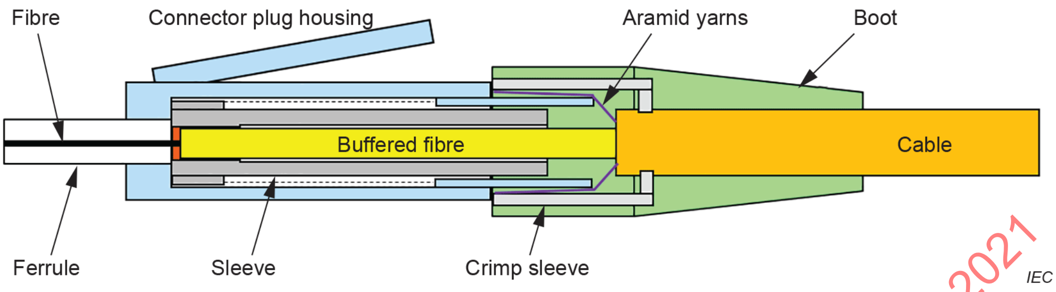


Figure D.3 – Simplex cable terminated at LC simplex connector

The design of physical contact connector types, such as SC, LSH, LC and others, includes a spring-loaded ferrule. As shown in Figure D.3, the fibre is epoxied into the ferrule as well as being cleaved and polished at the end face, and the buffered fibre (secondary coating) is affixed to the front part of the sleeve holding the ferrule. At the rear of the connector, the aramid yarns and the cable sheath are fixed in a defined position.

In this situation, no movement is possible between the fibre and the buffer. The spring pushes the sleeve holding the ferrule toward the front position, as shown in Figure D.4 a). During mating, the fibre of each connector is contacted physically to its counterpart. In the final mated condition, the connector ferrules move rearwards by several tenths of a millimetre, as shown in Figure D.4 b). For example for the LC connector type, the typical movement is 0,45 mm in each connector by the buffered fibre moving back into the cable sheath. The unguided buffered fibre (or fibre) is critical. Either the cable can accommodate that movement and/or the cable design can accommodate the buffered fibre over-length. If this movement is not considered, then the buffered fibre (or fibre) can buckle in the unguided zone, as indicated in dashed lines in Figure D.4 b), and can cause increased attenuation due to small bend radii.

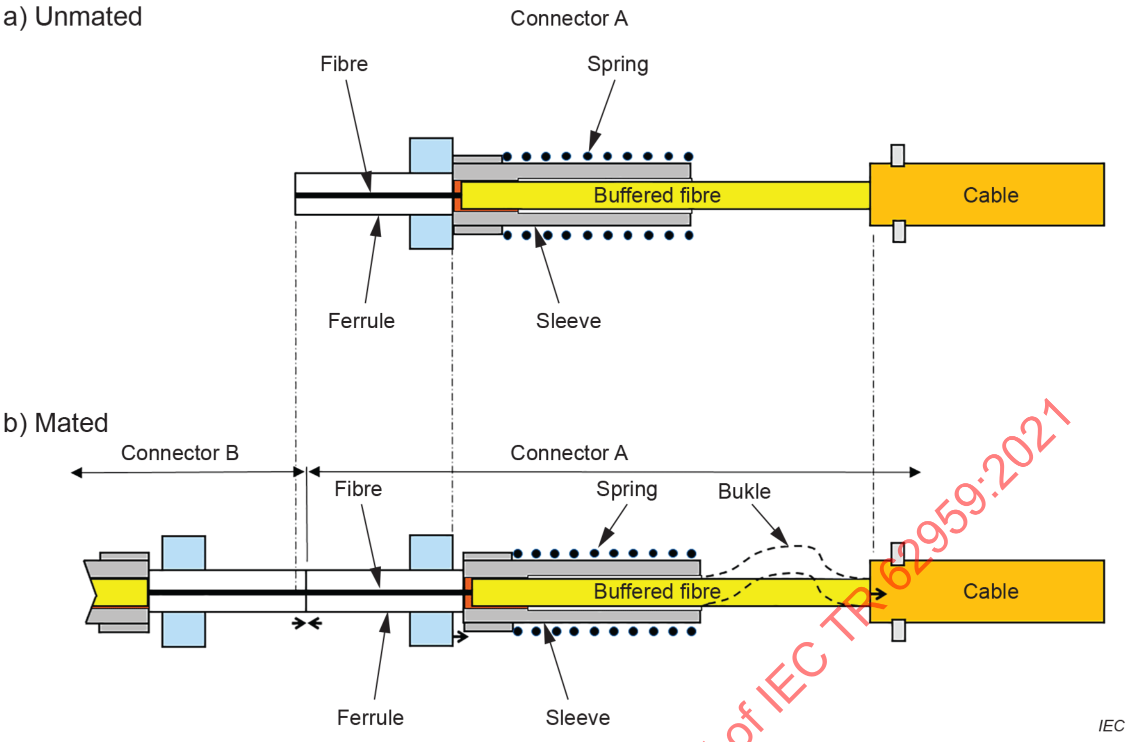


Figure D.4 – Fibre movement in spring-loaded connectors

The connector, fibre and cable type should be compatible so that no negative effects occur (see Clause D.4).

D.3 Simplex and duplex cable types

Several different simplex and duplex cable constructions exist on the market and they are designed for splicing and/or connector termination. IEC 60794-2-50 [17] shows different simplex and duplex cable types. In Clause D.3, simplex and duplex cables with semi-tight and tight buffered fibres (typically ∅ 0,9 mm) are considered as shown in Figure D.5 and Figure D.6.

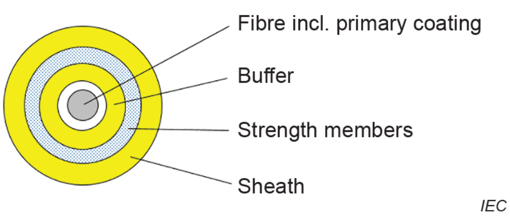


Figure D.5 – Simplex cable type

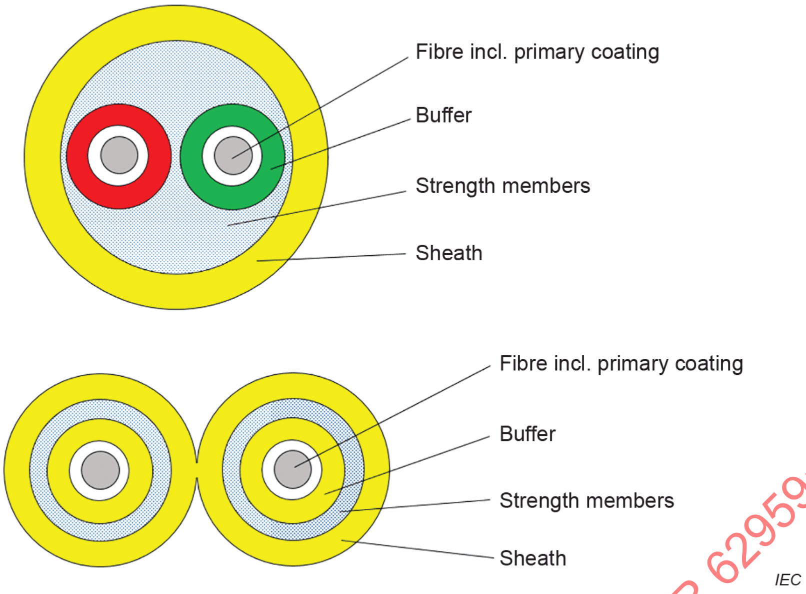


Figure D.6 – Duplex cable types

Other cable types exist for termination onto connectors, for example a duplex flat cable shown in IEC 60794-2-50 [17] and a breakout cable according to IEC 60794-2-22 [16]. The following cable types are not considered in Clause D.3:

– simplex and duplex cables without secondary coated fibre (without buffer);
– cable types with inner tubes and without any fibres, for a fan-out application.

These cable types require adapted considerations that are not covered in Clause D.3.

Cables are designed and manufactured to meet various mechanical, thermal, combustion, environmental, handling and installation requirements ensuring best optical performance. One out of many requirements is an easy termination that ensures a continuous low attenuation of the cable assembly [7].

The cable and the connector type should be compatible with each other so that no negative effects occur (see Clause D.4).

D.4 Termination of a cable to a connector

The fibre is usually fixed in the ferrule with epoxy that is located at the front of the connector. The buffered fibre is typically fixed into the sleeve holding the ferrule. The other cable elements, such as aramid yarns and cable sheath, are fixed at the rear of the connector. The cable fixing is not standardised, and every manufacturer can design it to their own requirements. Figure D.3 shows the typical situation of a simplex cable terminated into an LC simplex connector as a simplified representation.

The termination has to be done carefully, so that excessive stress that can cause attenuation or reliability concerns is not applied to the fibre in both the unmated and mated condition (see Clause D.2).

During temperature exposure and fluctuations, plastic materials change their dimensions both reversibly and irreversibly (see 5.2). Extruded plastic materials have an irreversible thermal contraction, so-called shrinkage (see 5.2.3).

If there is no overtravel accommodation in the cable, then significant forces between the cable elements are generated that can stress the fibre significantly and cause increased attenuation. If a cable element is unguided over a certain length, the weakest cable element (e.g. the buffered fibre) can buckle laterally, as shown by the dashed lines in Figure D.4 b). If the buckle causes very small bend radii, then increased attenuation can be observed.

Another effect can be that certain cable elements are pulled out of the fixing position (e.g. cable sheath).

To prevent the negative effects described above, the connector and cable type used should be compatible as explained below.

D.5 Overview of recommended cable tests

Table D.1 lists the recommended tests for cables to be used with connectors. All the tests marked with "recommended" in the third column of Table D.1 are covered in the simplex and duplex cable specification to be terminated with connectors (IEC 60794-2-50 [17]) and those marked with "indicator" can be used optionally. The last column in the table provides information about the tests and the application. The importance of a change of temperature with attenuation measurement test is especially highlighted.

Table D.1 – Recommended tests for cables to be terminated with connectors

Type of test	Test method	Use of test	Remark/Application
Change of temperature with attenuation measurement; Cable tested with fixed cable elements	IEC 60794-1-22, F12 [13]	Recommended	Best alternative for testing terminated product (IEC 61300-2-22 [22] and Annex J); See IEC 60794-2-50 [17]
Sheath pull-off force for cable for use in patch cords	IEC 60794-1-21, E21 [12]	Recommended	See IEC 60794-2-50
Buffer movement	IEC 60794-1-21, E22	Recommended	See IEC 60794-2-50
Stripping length of buffered fibres	IEC 60793-1-32 [10]	Recommended	See IEC 60794-2-50
Cable shrinkage	See 9.3.2	Indicator (optional)	Useful for a first and fast comparison between different cable types
Cable thermal expansion and contraction	See 9.3.3	Indicator (optional)	Useful before testing the cable for change of temperature with attenuation measurement
Forces of cable elements	See 9.3.4	Indicator (optional)	-

D.6 Main performance of a terminated cable

The main performance of a terminated cable is the optical transmission performance during environmental variations, i.e. during temperature changes. For that purpose, products should be tested using a suitable temperature cycling method while continuously measuring the change in attenuation during and after the test (see Clause D.7).

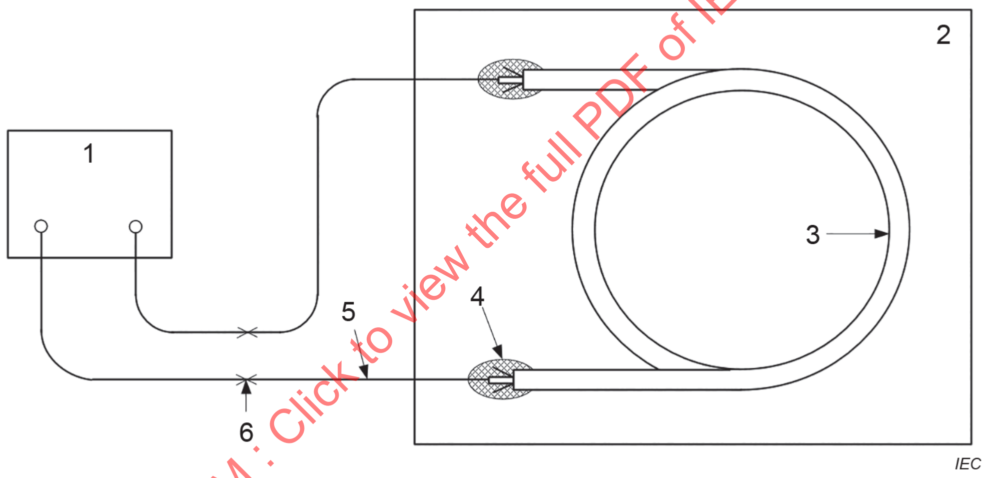
Low attenuation depends on many design parameters of the cable (see Clause D.3 and 5.3) as well as the type and quality of termination at the cable ends (see Clause D.4).

D.7 Guidance for change of temperature test methods

The direct way to test the suitability of the cable is to test the terminated product. To do that, the cable is terminated with connectors and tested. The main performance characteristic is the optical transmission behaviour during and after the change of temperature test. For verification, the complete terminated product should be tested using temperature cycling according to IEC 61300-2-22 [22]. During and after temperature cycling, the change in attenuation is measured at the specified wavelength(s). Additional visual examination shows if the product is still unchanged and undamaged after the test (see Annex J).

IEC 60794-2-50 [17] specifies a suitable alternative by testing the cable according to IEC 60794-1-22 [13], method F12, where all the cable elements at each cable end are fixed to each other to simulate a connector termination, as shown in Figure D.7. During and after the temperature cycling, any change in attenuation is recorded.

Method F12 of IEC 60794-1-22 [13] describes temperature cycling of a short length of cable intended for connectorisation. It does not specify a connectorised assembly. Rather, it simulates the cable portion by fixing the ends so that they cannot move. Thus, it assesses the attenuation portion of the assembly under a no-shrink/no-end movement condition. In the IEC cable specifications, no test methods are included for testing connectorised cable assemblies.



Key

1 attenuation measurement device

2 temperature chamber

3 cable sample, typically 10 m

4 all cable elements fixed at both ends, e.g. with glue

5 optical fibre

6 fibre connection (e.g. splice)

Figure D.7 – Test arrangement for method F12

The recommended test parameters for change of temperature testing are listed in Annex J. The allowable change in attenuation at the critical wavelength should be specified and measured where the fibre is most sensitive to stress [7]. For cables with single-mode fibres, the change in attenuation should be measured at 1 550 nm or 1 625 nm depending on the wavelength used in the application. For graded-index multimode 50 µm fibres, the change in attenuation should be measured at 850 nm, unless another wavelength is used in the application. The acceptance criteria for the change in attenuation during and after the test should be specified by the customer. If no requirements by the customer are specified, then the specified values in IEC 60794-2-50 [17] should be used. Failing to meet the optical requirements mean that the cable is not suited for the application in the tested operating environment.

Annex E
(informative)

Recommended tests for performance evaluation of cables to be terminated with hardened connectors

E.1 General

Annex E describes termination case no. 2 listed in 8.2 where hardened connectors are directly terminated onto cable ends, as shown in Figure E.1.

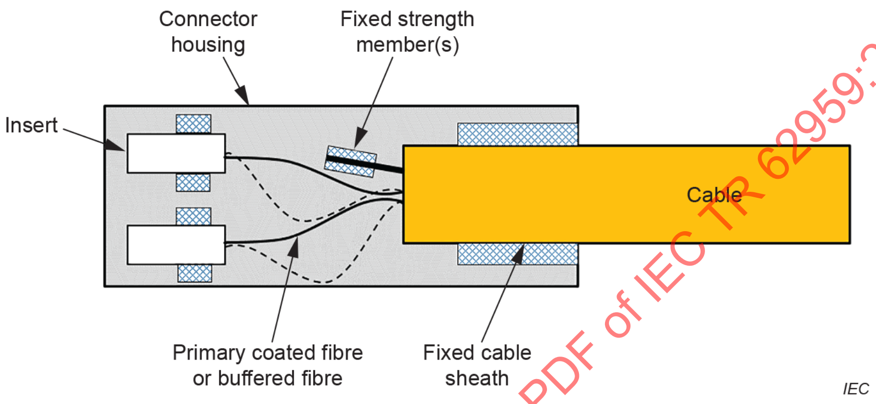


Figure E.1 – Cable terminated with hardened connector

Hardened connectors are used in outdoor environments (see IEC 61753-1 [23]) and industrial applications.

E.2 Connector types and design

Many different connector types and designs exist on the market varying in the number of fibres, the size, the shape and material of the housing, the type of coupling mechanism, the mechanical strength, the level of ingress resistance, etc. Some hardened connector types use inserts such as the LC duplex, MT ferrules or others as well as specifically designed inserts.

For making a connection, two connector variants are often required: a plug and a socket (male/female system). In Annex E, a hardened connector plug is considered, as shown in Figure E.1, that includes a housing for protection of the inserts and exposed fibres or buffered fibres and for cable fixing.

E.3 Cable types for hardened connectors

Typically, outdoor cable types containing single buffered fibres or with multi-fibre loose tubes are terminated into hardened connectors, but breakout and indoor-outdoor cables may also be used.

E.4 Termination of a cable to a hardened connector

Hardened connectors are terminated to the manufacturer's instructions. Typically, the inserts are terminated at the cable ends and the optical end faces are finalised. Subsequently, the inserts are mounted into the connector housing.

E.5 Overview of recommended cable tests

Table E.1 lists the recommended tests for cables to be used with hardened connectors. All the tests marked with "recommended" in the third column of Table E.1 are recommended to be specified and those marked with "indicator" can be used optionally. The last column in the table provides information about the tests and the application. The importance of a change of temperature with attenuation measurement test is especially highlighted.

Table E.1 – Recommended tests for cables to be terminated with hardened connectors

Type of test	Test method	Use of test	Remark/Application
Change of temperature with attenuation measurement; Cable terminated with hardened connectors	IEC 61300-2-22 [22]	Recommended	Hardened connectors should be within the temperature chamber
Sheath pull-off force	IEC 60794-1-21, E21 [12]	Recommended	
Buffer movement	IEC 60794-1-21, E22	Optionally recommended	If hardened connector cannot compensate buffer movement caused by inserts during mating
Stripping length of buffered fibres	IEC 60793-1-32 [10]	Recommended	Required length depending on insert type used
Stripping length of fibre tubes	Not available	Recommended	Required length depending on hardened connector used
Change of temperature with attenuation measurement; Cable tested with fixed cable elements	IEC 60794-1-22, F12 [13]; see Clause D.7	Indicator (optional)	Gives an indication of optical performance for the evaluation of possible cable types
Cable shrinkage (fibre protrusion)	See 9.4.2	Indicator (optional)	Useful for evaluation of possible cable types

E.6 Environmental performance of a terminated cable

The main environmental performance of a terminated cable is the optical transmission performance during extreme temperature changes. A set of cable samples terminated with connectors should be tested using temperature cycling according to IEC 61300-2-22 [22] with optical transmission monitoring. During and after temperature cycling, the change in attenuation is measured at the specified wavelength(s). Annex J provides recommended test parameters for change of temperature testing.

Annex F
(informative)

Recommended tests for performance evaluation of cables fixed into a module and fibres terminated with connectors

F.1 General

Annex F describes termination case no. 3 listed in 8.2 where connectors are terminated onto the fibres or buffered fibres of cables. After connector termination, the cable end is fixed at one side of a module, the fibres or buffered fibres are put into the free space in the module and the connectors are plugged into the adapters. Connectors used are for an indoor controlled or outdoor protected environment (see IEC 61753-1 [23]) and are described in more detail in D.2. Figure F.1 shows the cable terminated to connectors and fixed into a module.

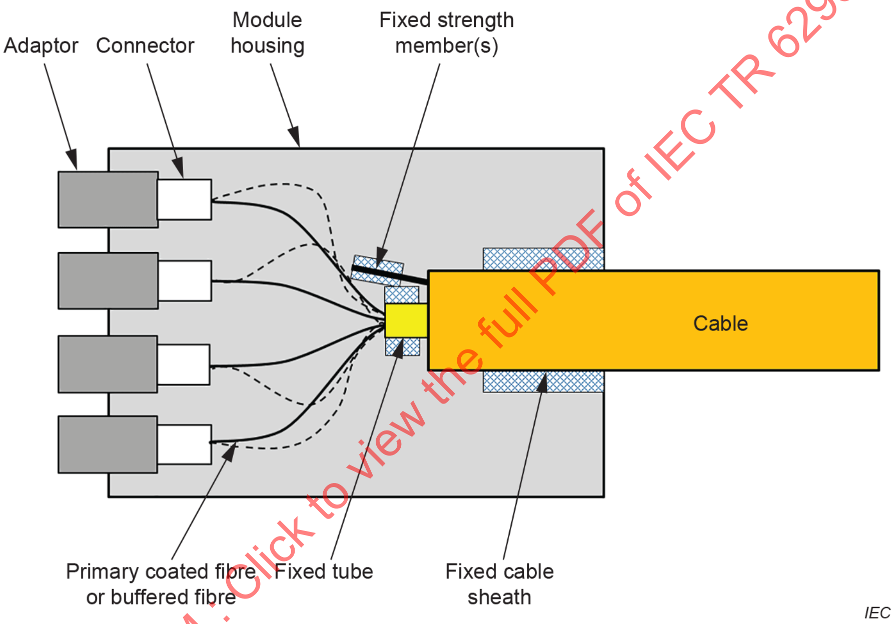


Figure F.1 – Cable fixed into a module and terminated with connectors

F.2 Connector types and design

See Clause D.2.

F.3 Cable types

Typically, indoor cable types containing multiple fibres, multiple buffered fibres or one multi-fibre loose tube are used for termination to modules.

F.4 Termination of a cable to a module

The fibres or the buffered fibres are terminated to connectors as explained in Clause D.4 but no aramid yarns and no cable sheath need to be fixed at the rear of the connector. The optical end faces of all connectors are finalised. Subsequently, the cable end is fixed at one side of a module, the fibres or buffered fibres are put into the free space in the module and the connectors are plugged into adapters.

F.5 Overview of recommended cable tests

Table F.1 lists the recommended tests for cables to be used with modules and fibres terminated with connectors. All the tests marked with "recommended" in the third column of Table F.1 are recommended to be specified and those marked with "indicator" can be used optionally. The last column in the table provides information about the tests and the application. The importance of a change of temperature with attenuation measurement test is especially highlighted.

Table F.1 – Recommended tests for cables fixed into module and terminated with connectors

Type of test	Test method	Use of test	Remark/Application
Change of temperature with attenuation measurement	IEC 60794-1-22, F1 [13]	Recommended	-
Stripping length of buffered fibres	IEC 60793-1-32 [10]	Recommended	See IEC 60794-2-50 [17]
Stripping length of fibre tubes	Not available	Recommended	Required length depending on module used
Change of temperature with attenuation measurement; Cable tested with fixed cable elements	IEC 60794-1-22, F12 [13]; see Clause D.7	Indicator (optional)	Gives an indication of optical performance for the evaluation of possible cable types
Cable shrinkage (fibre protrusion)	See 9.5.2	Indicator (optional)	Useful for evaluation of possible cable types

F.6 Main performance of a terminated cable

The main performance of a terminated cable is the optical transmission performance during environmental variations, i.e. during temperature changes. For that purpose, cables should be tested using temperature cycling according to IEC 60794-1-22 [13], method F1. During and after temperature cycling, the change in attenuation is measured at the specified wavelength(s). Annex J provides recommended test parameters for the change of temperature test.