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- **Central Marks Department III (CMD III)** - Technical Policy Matters on Certification of Engineering Products.
- **Think, Nudge and Move Department (TNMD)** - Standards Promotion, Consumer Awareness, Publicity and Enforcement.
- **Central Marks Department I (CMD I)** - General Policy Framework for Product Certification Activity and Matters related to Quality Control Orders (QCOs).
- **Electrotechnical Department (ETD)**- Standardization Activities in the field of Electrotechnology.
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From the Author

Bureau of Indian Standards (BIS), the National Standards Body of India established under the BIS Act 2016, has the responsibility of Formulation, Promotion and Implementation of National Standards, also known as Indian Standards.

Indian Standards published by BIS together with the Conformity Assessment Schemes form the basis of technical framework that helps Industry to build National Quality Ecosystem. The presence of BIS Standard Mark on a Product provides Third-Party Assurance of Quality, Safety and Reliability to Consumer.

The Nation is going through a phase of massive transformation in Quality Control scenario, requiring product compliance to Standards. The well-being of the Nation largely depends upon the work of the Engineer. "*Today's Engineers are the Nation Builders of Tomorrow*".

Electrical Engineering has a very broad scope, in practice and the text books have been specially designed with basic concepts and principles of Electrical Engineering. Even though textbooks are an invaluable component in building and broadening the knowledge base of every learner, students should have exposure to other types of Reference Books as alternate avenues for strengthening the already acquired knowledge.

This Reference Handbook integrates the learning methodology with practical aspects of testing, accommodating the rich experience contained in the relevant Indian Standards related to specific product. The blend of learning experience helps students to make the material more real and meaningful and intends to serve as a foundation to build a stronghold in the field of Electrical Engineering, thereby aiding them in delivering their role as an Electrical Engineer.

This Handbook draws on the extensive material base from latest Indian Standards available on the subject. The original text has been retained in the interest of providing necessary background to the continuing technical developments. However, users of this reference material are encouraged to refer latest editions of the Indian Standards to gain deep insight on various aspects of the subject. The indigenous Indian Standards can be downloaded free of cost from BIS website www.bis.gov.in or using the link https://standardsbis.bsbedge.com.

The Electrical Engineering Reference Handbook on Electric Cables and Overhead Electrical Conductors is an encyclopaedia and not a textbook for learners of Electrical Engineering and would not exist without **Shri Pramod Kumar Tiwari, IAS, Director General, BIS** whose conceptualization of the project on Reference Handbooks along with the vision, support and guidance have made this Handbook, along with so much else possible.

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INTRODUCTION

1.1 Introduction

The three major components of electrical power systems are: Generation, Transmission, and Distribution. The transmission system is responsible for linking generation side to substations, which in turn supply power to the consumers through distribution system.

With the increasing trend in global human population and the level of industrial development in developing countries including the spread of industrial activity, demand for electric power has increased considerably. A power plant produces electrical energy and the electrical power is then transmitted across long distances by high-tension power lines, which in turn is transported to users using overhead lines or underground cables. Thus, AC power transmission, distribution and utilization of electrical power may be through overhead lines or underground cables.

Overhead aluminium conductors form one of the major components of overhead transmission lines. Power cables which are mainly designed for a specific requirement are also used for transmission and distribution of electrical power. Electrical power cables may be installed as fixed, permanent wiring inside buildings or buried underground or run overhead. Flexible electrical power cables are used for portable devices, mobile tools, and machinery.

1.2 Indian Standards pave the way for Quality Upgradation

One of the major challenges faced by the developing countries is how to transmit and distribute electric power more efficiently. In India, the BIS helps to meet these challenges by publishing Indian Standards which facilitate the industry in manufacturing quality products conforming to the specified requirements of the relevant Indian Standards.

BIS has been developing Indian Standards that deal with various aspects of Electrotechnology through its Electrotechnical Department (ETD), which includes Standardization of electrotechnical aspects of generation, transmission, distribution. Standardizing the transmission and distribution of electricity through prescribing Indian Standards for Cables and Conductors, the most essential components of a power transmission network, is one of the fields where BIS makes a real difference to the future of the Nation in its quest for high quality products. The compliance of Cables and Conductors to Indian Standards aligns with the Government's aim to enhance product quality in the power sector, promote Indian manufacturing, encourage 'Made in India' products, and achieve self-reliance.

1.3 Relevant BIS Technical Committees

1.3.1 ETD 09 'Power Cables'

ETD 09 '*Power Cables*' Technical Committee prepares Standards for Electric Cables and their accessories.

Standards detailing the requirements of conductors, insulation and sheath are published by this committee, which includes:

(a) IS 5831 'PVC Insulation and Sheath of Electric Cables'

This Indian Standard specifies the physical and electrical requirements for PVC insulation and sheath of electric cables.

(b) IS 6380 ''Elastomeric Insulation and Sheath of Electric Cables'

This Indian Standard covers the physical and electrical requirements for elastomeric insulation and sheath of electric cables.

(c) IS 8130 'Conductors for Insulated Electric Cables and Flexible Cords'

This Indian Standard details the properties and construction of copper and aluminium conductors for insulated electric cables and flexible cords.

This technical committee publishes key product Standards which establish the specifications of different types of cables, as given below:

(a) **IS 694 'Polyvinyl Chloride (PVC) Insulated Unsheathed and Sheathed Cables/Cords with Rigid and Flexible Conductor for Rated Voltages up to and including 450/750 V'**

This Indian Standard covers general requirements of cables used in electric power and lighting including cables for outdoor and low temperature use.

(b) **IS 1554 series [IS 1554 (Part 1) and IS 1554 (Part 2)] 'PVC Insulated (Heavy Duty) Electric Cables'**

This Indian Standard series establishes the requirements and tests for Heavy Duty PVC cables for electric supply and control purposes as given below:

- ***IS 1554-1: For cables up to & including 1100 V***
- ***IS 1554-2: For cables from 3.3 kV up to and including 11 kV***

(c) **IS 7098 series [IS 7098 (Part 1), IS 7098 (Part 2) and IS 7098 (Part 3)] 'Cross-linked Polyethylene Insulated PVC Sheathed Cables'**

This Indian Standard series specifies the requirements for Cross-linked Polyethylene (XLPE) cables for electric supply and control purposes as given below :

- ***IS 7098-1: For cables up to & including 1100 V***
- ***IS 7098-2: For cables from 3.3 kV up to and including 33 kV***
- ***IS 7098-3: For cables from 66 kV up to and including 220 kV***

(d) **IS 9968 series [IS 9968 (Part 1) and IS 9968 (Part 2)] 'Elastomer Insulated Cables'**

This Indian Standard series gives requirements of elastomeric cables for fixed wiring, flexible cables and flexible cords for electric power and lighting as given below:

IS 9968-1: For cables up to & including 1100 V

IS 9968-2: For cables from 3.3 kV up to and including 33 kV

(e) **IS 14255 'Aerial Bunched Cables for working voltages up to and including 1100 V'**

This Indian Standard covers the requirements of polyethylene/ cross-linked polyethylene insulated cables with aluminium conductors twisted over a central bare/ insulated aluminium alloy messenger wire for use as overhead distribution feeders.

(f) **IS 16246 'Elastomer Insulated Cables with limited circuit integrity when affected by fire'**

This Indian Standard specifies the requirements of heat resisting elastomer insulated cables for fixed installations for single phase and three phase systems suitable for operation at voltages up to and including 1100V, for maintaining limited circuit integrity when affected by fire.

(g) **IS 17048 'Halogen Free Flame Retardant (HFFR) Cables for working Voltages up to and including 1100 V'**

This Indian Standard specifies the general requirements of HFFR cables used in power and lighting installations including cables for low temperature applications.

(h) **IS 17293 'Electric Cables for Photovoltaic Systems for rated voltage 1500 V d.c.'**

This Indian Standard details the requirements of single core cables for use in photovoltaic (PV) systems for installation at the direct current (d.c.) side.

(i) **IS 17505 (Part 1) 'Thermosetting Insulated Fire Survival Cables for fixed installation having low emission of smoke and corrosive gases when affected by fire for working Voltages up to and including 1100 V AC and 1500 V DC - Requirements for Armoured Cables'**

This Indian Standard covers the requirements of thermosetting insulated armoured fire survival cables for maintaining circuit integrity when affected by fire.

ETD 09 also issues the following Indian Standards on testing of cables:

(a) **IS 10810 series [IS 10810 (Part 0) to IS 10810(Part 64)] 'Methods of Test for Cables'**

This Indian Standard series comprise the core publications covering all aspects related to testing of cables. A large number of Indian Standards have been published by BIS specifying the distinct requirements for various types of electric cables. IS 10810 includes different parts, each part dealing with a particular test in detail. This Standard, issued in different parts, prescribes methods of tests for electric cables, wires and cords in finished stage as well as their components such as conductor, insulation, sheath and armour. Besides providing consolidated details at a place, this standard avoids repetition and brings uniformity in testing of cables.

1.3.2 ETD 37 'Conductors and Accessories for Overhead Lines Technical Committee'

ETD 37 '*Conductors and Accessories for Overhead Lines'* Technical Committee prepares Standards for Conductors and accessories for overhead power lines.

This technical committee issues key Standards required for overhead transmission purposes such as, the following:

(a) IS 398 series [IS 398 (Part 1), IS 398 (Part 2), IS 398 (Part 3), IS 398 (Part 4), IS 398 (Part 5) and IS 398 (Part 6)] 'Aluminium Conductors for Overhead Transmission Purposes'

This Indian Standard series specifies the requirements and tests for aluminium conductors used for overhead power transmission purposes.

IS 398-1: For aluminium stranded conductors

IS 398-2: For aluminium conductors, galvanized steel reinforced

IS 398-3: For aluminium conductors, aluminized steel reinforced

IS 398-4: For aluminium alloy stranded conductors (Aluminium - Magnesium - Silicon Type)

IS 398-5: For aluminium conductors, galvanized steel reinforced for extra high voltage (400 kV and above)

IS 398-6: For high conductivity aluminium alloy stranded conductors

1.4. Overview of Cables and Conductors in the Reference Handbook

Various types of energy cables are covered in this reference handbook, from wiring and flexible cables for general use to cables used in distribution and transmission. It gives information on materials, construction, types of insulation and sheath, composition, etc.

Many aspects of cable testing are common to all types and hence testing of cables which are reasonably applicable to most cables is also dealt with in this reference handbook.

Recognising the increasing impact of cables with improved fire performance, description of cables in fires w.r.t performance characteristics is an important highlight of this handbook.

Further, extensive tables of data on commonly used cable types are also included for guidance and reference and the tabular data presented provides information on the range of cables and their properties available in the most widely used fields.

Furthermore, several types of overhead electrical conductors are also covered in this reference material, which includes the details on materials, construction, testing etc.

In a nutshell, we learn about different types of electric cables, requirements for their insulation and sheath, and various types of electrical conductors for overhead transmission purposes, looking through the viewpoint of Indian Standards and bringing a Standards perspective into the subject.

1.5 Idea of the Handbook

1.5.1 The Background of the Handbook

Textbooks are integral components of any study that enrich the learning of students. The large scale application of theory in the field may not yield the desired results always and one of the reasons for this is the fragmentation of knowledge due to practical considerations.

As Agatha Christie stated: "*To every problem, there is a most simple solution.*" It is from these words of wisdom that the idea about selecting the topic on '***Electric Cables and Overhead Electrical Conductors***' for the Electrical Engineering Reference Handbook emerged.

In BIS, the Standardization activities are carried out by specialized Technical Committees which comprises stakeholders representing various interests. The whole gamut of standardization eco-system is based on active participation and contribution of domain area experts and their rich knowledge acquired through learning from experiences getting incorporated into Indian Standards.

The theory learned by students from text books need to be supplemented for capacity building through the field level knowledge embedded in the rich contents of the published Indian Standards. It was within the framework of assimilation and amalgamation of information on various types of cables and conductors contained in multitude of Indian Standards, this Handbook on Electrical Engineering having reference to Electric Cables and Overhead Electrical Conductors was initiated.

1.5.2 The Structure of the Handbook

The Handbook consists of four chapters.

Chapter I elaborate on the role of electric cables and overhead conductors in electric power transmission and distribution. The mandate of BIS on harmonious development of standardization and quality control and the details of Indian Standards on Cables and Conductors are also explained. It further describes the idea behind the Handbook with due emphasis on the structure of the Handbook as well as the contents.

Chapter II deals with electric cables where the details of materials for manufacturing of cables including that of the insulation and sheath, various types of cables, testing of conductors for cables as well as testing of insulation and sheath along with the provisions given in the Indian Standards on the subject are explained. The specific requirements and test methods for cables with improved fire performance characteristics are also elucidated in this chapter.

In **Chapter III** different types of overhead electrical conductors, materials used for construction, test requirements etc. are briefly explained along with the set of requirements specified in the Indian Standards.

Chapter IV makes a reference to the regulatory role of Indian Standards and amplifies how Technical Regulations notified by the Central Government that corresponds to the relevant Indian Standards impact the quality culture of the country. This chapter also sheds light on the role of BIS in ensuring quality of products and how benefits are derived across different segments of stakeholders through product compliance to Indian Standards.

1.5.3 The Contents of the Handbook

There exists a large number of Indian Standards on Cables and Conductors which encompasses the set of requirements and parameters, the compliance of which is essential for different varieties of cables and conductors that are used in the field. The chapters on electric cables and overhead conductors refer to the related Indian Standards as well as the cross-referred Indian Standards giving the complete details of the product and its testing. The references and the contents become crucial for the future engineers of Electrical discipline to stay updated with the evolving technical framework on cables and conductors and the role of Indian Standards to ensure compliance of these products. The contents of this Handbook are intended to enable learning from exemplary industry experiences engraved in Indian Standards and try to overcome the gaps between knowledge production in academia vis-à-vis industry practices, thereby moulding the technical acumen of the learner by understanding the subject viewing through the lens of Indian Standards.

CHAPTER II

ELECTRIC CABLES

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ELECTRIC CABLES

2.1 Conductors for Electric Cables

Copper or Aluminium conductors are used in the construction of various types of electric cables and flexible cords.

BIS has published the following Indian Standard for conductors in electric power cables and cords of a wide range of types:

IS 8130 'Conductors for Insulated Electric Cables and Flexible Cords'

This Indian Standard specifies the properties and construction of copper and aluminium conductors for insulated electric cables and flexible cords. The nominal cross-sectional areas in the range 0.5 mm^2 to 2500 mm^2 are specified in this Standard. Requirements for numbers and sizes of wires and resistance values are also included. These conductors include solid and stranded, copper and aluminium conductors in cables for fixed installations, flexible conductors and welding cables.

The different requirements are detailed in various clauses of IS 8130 as given below:

- Material for conductors - Clause 4
- Classification of conductors - Clause 5
- Construction - Clause 6
- Tests for conductors - Clause 7

The specific requirements are elaborated as given under:

2.1.1 Material and Form

All types of electric cable consist essentially of a low resistance conductor to carry current.

Copper conductors shall be tinned or untinned annealed and made from high conductivity copper rods with conductivity 99.25% International Annealed Copper Standard (IACS).

Aluminium shall be plain with grades and tensile strength as given in Table 2.1. For shaped solid conductors and welding cable conductors, only Grade 0 aluminium shall be used. For conductors of cross-sectional area up to and including 10 mm^2, H2 or H4 Grade aluminium shall be used and for remaining conductors, aluminium of Grade 0, H2 or H4 may be used.

Table 2.1 Tensile Strength requirement of Aluminium Conductor

(Clause 4.1 of IS 8130)

Grade	Tensile Strength, N / mm^2
0	Up to and including 100
H2	Above 100 and up to and including 150
H4	Above 150

The form of conductor can be solid, circular, shaped, compacted, stranded or bunched as required by the construction specified for the particular type of cable. The conductor shall be clean, reasonably uniform in size and shape, smooth and free from harmful defects. Joints are permitted in the individual wires of which the conductor is formed, but no joint shall be within 300 mm of any other joint within the same layer. For stranded conductors, joints shall be made by resistance butt welding, fusion welding, cold pressure welding, electric welding, gas welding, brazing or silver soldering. For solid conductors (aluminium conductors only) no joints shall be made in the finished solid conductor.

2.1.2 Flexibility Class and Construction

The conductors are divided into four classes as given below:

a) Cables for Fixed Installations - Class 1 and Class 2

b) Flexible Cables - Class 5 and Class 6

The types of construction for the various class of conductors are as follows:

(a) Solid Conductor (Class 1)

The conductor shall consist of single wire of plain or tinned annealed copper or plain aluminium.

The solid copper conductors having nominal cross-sectional areas of 25 mm^2 and above are intended for particular types of cables only and not for general purpose. Solid copper conductor shall be of circular cross section.

Solid aluminium conductor of sizes from 1.5 mm^2 up to & including 35 mm^2 shall be of circular cross section and sizes 35 mm^2 & above may be of either circular or shaped cross-section.

(b) Stranded Circular Non-Compacted Conductors (Class 2)

Conductor shall consist of plain or tinned annealed copper or plain aluminium. The wires in the conductor shall have the same nominal diameter before stranding. The number of wires in the conductor shall be not less than the minimum number as specified.

(c) Stranded Compacted Circular Conductors and Shaped Conductors (Class 2)

Conductor shall consist of plain or tinned annealed copper or plain aluminium. The ratio of diameters of two wires before stranding in the same conductor shall not exceed 2. The number of wires in the conductor shall be not less than the minimum number as specified.

(d) Flexible Conductors (Class 5 and Class 6)

Conductor shall consist of plain or tinned annealed copper. The wires in the conductor shall have same nominal diameter before bunching. The diameter of the wires in any conductor shall not exceed the maximum value as specified.

2.1.3 Tests for Conductors

The following tests are to be carried out on conductors:

(a) Persulphate Test (for Copper only)

The following Indian Standard details the procedure for Persulphate test on copper conductors:

IS 10810 (Part 4) 'Methods of Test for Cables - Persulphate Test of Conductor'.

The method for determining exposed copper in case of tinned copper wire for conductors used in electrical cables is explained in various clauses as given below:

- Apparatus - Clause 4
- Reagents - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The mass of copper dissolved from the wire by the persulphate solution is determined colorimetrically by comparison with the standard colour reagent and is expressed as grams of copper per square metre of wire immersed in the persulphate solution.

The mass of copper dissolved shall not exceed 5 g/m^2 for wire diameter up to and including 0.41 mm and 3 g/m^2 for wire diameter above 0.41 mm.

Significance

The objective of Persulphate test is to determine the exposed copper in case of tinned copper wire. Copper wires are tinned to act as a barrier between bare copper conductor and elastomeric insulations to avoid degradation of the insulation due to catalytic effect of copper on elastomers. Tinning also avoid formation of oxide on the copper conductor which reduces the solder ability of the material. During the tinning process of copper, there is possibility of formation of pinholes on the conductor, thereby defeating the purpose of application of tin. The persulphate test on tinned copper wire determines the exposed copper, thereby ascertaining the continuity of tin coating on the conductors.

(b) Tensile Test (for Aluminium only)

The following Indian Standard details the procedure for tensile test on aluminium conductors:

IS 10810 (Part 2) 'Methods of Test for Cables – Tensile Test for Aluminium Wires'

The method for determining tensile strength of aluminium wires used for conductors of electric cables is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5

- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The test is carried out using tensile testing machine having grips to hold the specimen firmly. The test specimen for measurement of tensile strength is the wire (before stranding and after stranding) which is used as conductor of the cable. The gauge length (original length of that portion of the test specimen over which strain is determined) for measurement of tensile strength of wire shall be 250 mm. The total length of specimen shall be at least equal to gauge length plus length of wire required for full use of grips of the machine. For circular specimen, diameter is measured. For shaped solidal conductor specimen, mass and length of specimen are determined.

The test specimen is fixed between the two heads of tensile testing machine by means of grips. The load is applied gradually and uniformly to the wire having an original gauge length of 250 mm till it gets fractured. The rate of elongation or rate of separation of two heads shall not be greater than 100 mm/min. When the test specimen fractures, breaking load is noted down and tensile strength is calculated. The observations shall be tabulated as given in Table 2.2.

Table 2.2 Tensile test – Aluminium Conductor

Diameter of circular wire (mm)	Shaped Solidal Conductor		Cross Sectional Area (mm²)	Breaking Load (N)	Tensile Strength (N/mm²)
	Mass (gram)	Length (mm)			

Calculations

Area of Circular Specimen (mm²) = $\frac{\pi}{4} \times d^2$

where, d = diameter of specimen in mm.

Area of Shaped Solidal Conductor (mm) = $\frac{1000m}{2.703L}$

where, m = mass of specimen in g, and L = length of specimen in mm.

$$\text{Tensile Strength (N/mm}^2\text{)} = \frac{\text{Breaking Load in N}}{\text{Area of Cross Section of Specimen in mm}^2}$$

The tensile strength of any wire (before stranding) shall comply with values given in Table 2.1. For wires taken after stranding, tensile strength of any of the wires shall be not less than 95 percent of the minimum values given in Table 2.1. The test for wires taken from stranded conductors is not applicable in case of compacted circular conductors or shaped conductors.

> ***Significance***
>
> ***Conductors of cables are subjected to considerable force during manufacturing as well as due to pulling from one end along trenches during laying of cables. This test is performed on conductor material to determine the strength of material when subjected to tensile stress. The tensile test which is performed on aluminium wires verifies the strength of aluminium wire sample and the test results shows if the conductor material tensile strength is adequate or not.***

(c) Wrapping Test (for Aluminium only)

The following Indian Standard details the procedure for wrapping test on aluminium conductors:

IS 10810 (Part 3) 'Methods of Test for Cables – Wrapping test for Aluminium Wires'

The method for determining ductility of aluminium wire used as conductors for electric cable is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The conductor wire shall be wrapped round its own diameter to form a close helix of six turns. These turns shall then be unwrapped and again closely re-wrapped in same direction as before. The wire is said to have passed the test, if the wire does not break.

> ***Significance***
>
> ***During the manufacturing and installation process, cable conductors are subjected to torsion caused by axial twisting resulting on possible breakage if the material is not sufficiently ductile. Wrapping test performed on a sample of aluminium wire determines its ductility; the properties of how easily the material can be twisted and wrapped without breaking. Thus performing wrapping test on an aluminium conductor sample brings out the property of the material, which makes it suitable for winding and twisting. During the test, if the sample wire does not break it is deemed as ductile thereby ensuring the suitability of material as cable conductor.***

(d) Annealing Test (for both Copper and Aluminium)

The following Indian Standard details the procedure for annealing test on conductors:

IS 10810 (Part 1) 'Methods of Test for Cables - Annealing Test for Wires used as Conductors'

The method for determining elongation properties of annealed copper wires, aluminium wires for welding cables and solidal conductors used in electric cables is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The test is carried out using tensile testing machine having grips to hold the specimen firmly. The test specimen for measurement of elongation is the wire (before stranding) which is used as the conductor of the cable. Gauge length (original length of that portion of test specimen over which change of length is determined) for measurement of elongation of wire shall be 250 mm. The total length of specimen shall be at least equal to gauge length plus length of wire required for full use of grips of the machine. The specimen shall be straightened by hand, if necessary and gauge marks shall be scribed lightly with dividers or drawn with ink.

The test specimen is fixed between the two heads of tensile testing machine by means of grips. The load is applied gradually and uniformly to the wire having an original gauge length of 250 mm till it gets fractured. The rate of elongation or rate of separation of two heads shall not be greater than 100 mm/min. The elongation is measured on the gauge length after the fractured ends have been fitted together. The observations shall be tabulated as given in Table 2.3.

Table 2.3 Annealing Test

Diameter of circular wire (mm)	Size of shaped solidal conductor (mm^2)	Original Gauge Length L_1 (mm)	Length after fracture L_2 (mm)	Elongation $L = L_2 - L_1$ (mm)	%Elongation $= \frac{L}{L_1} \times 100$

For copper conductors the elongation shall be not less than the value given in Table 2.4.

Table 2.4 Elongation requirement of Copper Conductor

(Clause 7.1.2.1 of IS 8130)

Wire Diameter		Elongation (Min)
Over (mm)	Up to and Including (mm)	Percent
-	0.21	9.0
0.21	0.41	13.5
0.41	1.36	18.0
1.36	-	22.5

For aluminium conductors, the elongation shall be not less than the following:

- 25 percent - for shaped solid conductors
- 12 percent - for wires of conductor for welding cables

Significance

During construction/ installation procedures, the conductor of a cable is subjected to twisting and bending. Annealing test takes into consideration the extent of work hardening which may be caused during stranding and laying up process. This test which is carried out on a conductor sample prior to installation subjects the conductor to a tensile test which will elongate the sample. The test results show whether or not the conductor meets the specified allowed elongation for that particulate gauge which is a clear indication of whether the conductor is flexible enough to take any desired bend without breaking.

(e) Resistance Test (for Both Copper and Aluminium)

The following Indian Standard details the procedure for Resistance test:

IS 10810 (Part 5) 'Methods of Test for Cables – Conductor Resistance Test'

The method for determining the dc resistance of conductors is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

This test is to be done on finished conductors. The dc resistance of conductor is measured at room temperature and corrected to 20°C by means of appropriate temperature correction factors.

The apparatus used is Kelvin double bridge or Wheatstone bridge or any digital meter. For resistance values up to 1Ω, only kelvin double bridge shall be used. The drum length of cable or sample length of cable or conductor as indicated in Table 2.5 shall constitute the test specimen.

Table 2.5 Resistance test on Conductor – Test specimen requirements

(Clause 6.1 of IS 10810-5)

Type of Cable/ Conductor	Test Specimen
All solid circular conductor	Drum length or 1 m
All stranded/sector shaped solid conductors upto and including 25 mm^2	Drum length or 5 m
All stranded or sector shaped solid conductors greater than 25 mm^2	Drum length or 10 m

The test specimen, after attaining ambient temperature, is connected to resistance measuring bridge. Adequate care is to be taken in this connection to minimize contact resistance. The resistance of test specimen is measured and ambient temperature recorded. During resistance measurement, the magnitude of current shall be such that there is no heating up of test specimen. The measured resistance is converted to standard temperature and standard length. The observations shall be tabulated as given in Table 2.6.

Table 2.6 Resistance test on Conductor

Nominal conductor size (mm^2)	Length (mm)	Material (Al/ Cu)	Class of conductor	Temperature 't' (°C)	Observed resistance (Ω)	Calculated resistance at 20°C in (Ω/km)

Calculation:

$$\text{Calculated resistance at } 20^\circ \text{ C, R} = \frac{Rt \times k}{L} \times 1000\ \Omega/\text{km}$$

where, R_t = observed resistance at t°C, k = temperature correction factor and

L = length of test specimen in m.

The corrected dc resistance shall not exceed the values as given in IS 8130 for various types of cables for each specified nominal cross sectional areas of conductor.

Significance

Accurate control of resistance is necessary to meet system design parameters. Resistance is influenced by conductor dimensions and construction, processing conditions, temperature and resistivity (composition/impurities and temper of material). The resistance test that is performed on conductors determines the direct current resistance of the wire (expressed in terms of ohms per kilometre corrected to 20°C). The results based on a calculation of observed resistance, particular temperature, sample length etc. will conclude how easily the current will flow through the wire.

2.2 Types of Insulation and Sheath and Composition

Electric Cables mainly consists of three main components, namely, conductor, insulation and sheath. The conductor provides path for electric current. Insulation is assembly of insulating materials incorporated in a cable with specific function of withstanding voltage. Insulation also protects conductor from coming into contact with other conductors and protects from environmental conditions of moisture and heat. Sheath of cable is the protective covering over insulation that protects cables from all external influences of surroundings. The arrangement of insulation and sheath on a cable depends on voltage and service application of the cable.

BIS has published the following Indian Standard on PVC insulation and Sheath of cables:

IS 5831 'PVC Insulation and Sheath of Electric Cables'.

This Indian Standard specifies the physical and electrical requirements for PVC insulation and sheath of electric cables. This standard brings various requirements for PVC insulation and sheath of different types of cables under a single cover and is complementary to the individual Indian Standards for different types of cables.

The various requirements are detailed in the particular clauses of IS 5831 as given below:

- Composition - Clause 4
- Test Requirements - Clause 5

Some of the different types of insulation and sheath used in construction of various types of cables are described below:

(a) Polyvinyl Chloride (PVC) compound

PVC compound consists of combination of materials suitably selected, proportioned and treated, of which the characteristic constituent is plastomer polyvinyl chloride or one of its copolymers of which major constituent is vinyl chloride. The different types of PVC insulation and sheath and some important properties are given in Table 2.7, Table 2.8 and Table 2.9.

Table 2.7 Types of PVC Insulation and Sheath

(Clause 1.2 of IS 5831)

Type	Characteristics
Type A	General purpose insulation for maximum rated conductor temperature 70°C intended for cables with rated voltages U_0/U up to and including 3.3/3.3 kV.
Type B	General purpose insulation for maximum rated conductor temperature 70°C intended for cables with rated voltages U_0/U above 3.3/3.3 kV.
Type C	Heat resisting insulation for maximum rated conductor temperature 85°C intended for cables with rated voltages up to and including 1100 volts.
Type D	General purpose insulation for maximum rated conductor temperature 70°C intended for flexible cables with rated voltages U_0/U up to and including 3.3/3.3 kV.
Type ST1	General purpose sheath intended for use in cables operating at a maximum rated conductor temperature 70°C.
Type ST2	Heat resisting sheath intended for use in cables operating at a maximum rated conductor temperature 90°C.
Type ST3	General purpose sheath intended for use in flexible cables operating at a maximum rated conductor temperature 70°C.

Table 2.8 PVC Insulation Properties

(Table 1 under Clause 4.1 of IS 5831)

Property	Unit	Type of Insulation			
		A	B	C	D
Volume Resistivity, min					
at 27° C	Ω-cm	1×10^{13}	1×10^{14}	1×10^{13}	1×10^{12}
at maximum rated temperature	Ω-cm	1×10^{10}	1×10^{11}	1×10^{10}	1×10^{9}
Insulation Resistance Constant, min					
at 27° C	MΩ km	36.7	367	36.7	3.67
at maximum rated temperature	MΩ km	0.037	0.37	0.037	0.004
Without ageing					
Tensile strength, min	N/mm^2	12.5	12.5	12.5	10
Elongation at break, min	percent	150	135	125	150
After ageing in air oven					
Treatment					
Temperature (tolerance ± 2°C)	°C	80	100	135	70
Duration	days	7	7	7	7

Property	Unit	Type of Insulation			
		A	B	C	D
Tensile Strength					
Value after ageing, min	N/mm^2	12.5	12.5	12.5	10
Variation, max	percent	±20	±25	±25	±20
Elongation at break					
Value after ageing, min	percent	150	125	125	150
Variation, max	percent	±20	±25	±35	±20
Loss of Mass in air oven					
Treatment					
Temperature (tolerance ± 2°C)	°C	80	-	-	80
Duration	days	7	-	-	7
Loss of mass, max	mg/cm^2	2	-	-	2
Hot Deformation					
Temperature (tolerance ± 2°C)	°C	80	80	95	80
Time under load (see note)					
First case	hours	4	4	4	4
Second case	hours	6	6	6	6
Depth of indentation, max	percent	50	50	50	65
Heat Shock					
Treatment					
Temperature (tolerance ± 2°C)	°C	150	150	150	150
Duration	hours	1	1	1	1
Visual	No signs of cracks or scales				
Shrinkage					
Treatment					
Temperature (tolerance ± 2°C)	°C	150	150	150	150
Duration	minutes	15	15	15	15
Shrinkage, max	percent	4	4	4	6

Note: ***Time under load*** *- First case for cables having rated voltage not exceeding 3.3/3.3 kV and conductor cross-section not exceeding 35 mm^2. Second case for those not covered under first case.*

Table 2.9 PVC Sheath Properties

(Table 1 under Clause 4.1 of IS 5831)

Property	Unit	Type of Sheath		
		ST1	ST2	ST3
Without ageing				
Tensile strength, min	N/mm^2	12.5	12.5	10
Elongation at break, min	percent	150	150	150
After ageing in air oven				
Treatment				
Temperature (tolerance ± 2°C)	°C	80	100	80
Duration	days	7	7	7
Tensile Strength				
Value after ageing, min	N/mm^2	12.5	12.5	10
Variation, max	percent	±20	±25	±20
Elongation at break				
Value after ageing, min	percent	150	150	150
Variation, max	percent	±20	±25	±20
Loss of Mass in air oven				
Treatment				
Temperature (tolerance ± 2°C)	°C	80	100	80
Duration	days	7	7	7
Loss of mass, max	mg/cm^2	2	2	2
Hot Deformation				
Test temperature (tolerance ± 2°C)	°C	80	80	70
Time under load				
First case	hours	4	4	4
Second case	hours	6	6	6
Depth of indentation, max	percent	50	50	65
Heat Shock				
Treatment				
Temperature (tolerance ± 2°C)	°C	150	150	150
Duration	hours	1	1	1
Visual	No signs of cracks or scales			
Shrinkage				
Treatment				
Temperature (tolerance ± 2°C)	°C	150	150	150
Duration	minutes	15	15	15
Shrinkage, max	percent	4	4	6

Note: ***Time under load*** *- First case for test piece having outer diameter not exceeding 12.5 mm. Second case for test piece having outer diameter exceeding 12.5 mm.*

(b) Elastomer Compound

The different types of elastomer insulation and sheath are given below:

i) Insulation and Sheath for General Service (IE 1, SE 1 and SE 2): It consists of elastomeric compound in which characteristic constituent is natural or synthetic elastomer, or a mixture of two.

ii) Heat Resisting Insulation (IE 2 and IE 3): It consists of elastomeric compound based on synthetic rubber (ethylene propylene rubber or polyalkane rubber of ethylene propylene type or similar polymer).

iii) Oil Resisting and Flame Retardant Insulation (IE 4): It consists of elastomeric compound based on chlorosulphonated polyethylene or equivalent.

iv) Heat Resisting Sheath (SE 3 and SE 4): It consists of elastomeric compound in which characteristic constituent shall be polychloroprene, chlorosulphonated polyethylene or NBR-PVC blends or other suitable synthetic rubber.

v) Silicon Rubber Insulation and Sheath (IE 5 and SE 5): It consists of elastomeric compound in which characteristic constituent is silicon rubber.

The maximum rated operating temperature of conductor for different types of elastomeric insulation and sheath and some important requirements are given in Table 2.10, Table 2.11 and Table 2.12.

Table 2.10 Elastomeric Insulation and Sheath – Types and Temperature Rating

(Table 1 under Clause 1.2 of IS 6380)

Type of Insulation/Sheath	**Type Reference**	**Maximum Rated Operating Temperature of Conductor**
Insulation for general service	IE1	60 °C
Heat resisting insulation:		
a) suitable for voltages up to 1100 V	IE2	90 °C
b) suitable for voltages above 1100 V	IE3	90 °C
c) oil resisting and flame retardant insulation suitable for voltages up to 1100 V	IE4	90 °C
Silicon rubber insulation	IE5	150 °C
Sheath for general service:		
a) normal duty	SE1	60 °C
b) heavy duty	SE2	60 °C
Heat resisting, oil resisting and flame retardant elastomer sheath:		
a) normal duty	SE3	90 °C
b) heavy duty	SE4	90 °C
Silicon rubber sheath	SE5	150 °C

Table 2.11 Elastomeric Insulation Properties

(Table 2 under Clause 1.2 of IS 6380)

Property	Unit	IE1	IE2	IE3	IE4	IE5
Insulation Resistance Constant, min						
at 27°C	M Ω km	700	3670	3670	10	870
at maximum rated temperature	M Ω km	-	3.67	3.67	-	-
Without ageing						
Tensile strength, min	N/mm^2	5.0	4.2	4.2	7.0	5.0
Elongation at break, min	percent	250	200	200	200	150
After ageing in air oven						
Treatment						
Temperature (tolerance ±2°C)	°C	70	135	135	135	200
Duration	days	10	7	7	7	10
Tensile strength, variation, max	percent	±40	±30	±30	±50	±20
Elongation at break, variation, max	percent	±40	±30	±30	±50	±20
After ageing in air bomb						
Treatment						
Temperature (tolerance ±1°C)	°C	-	127	127	127	-
Duration	hours	-	40	40	40	-
Pressure (tolerance ±0.02 MPa)	MPa	-	0.55	0.55	0.55	-
Tensile strength, variation, max	percent	-	±30	±30	±50	-
Elongation at break, variation, max	percent	-	±30	±30	±50	-
After ageing in oxygen bomb						
Treatment						
Temperature (tolerance ±1°C)	°C	70	-	-	-	-
Duration	hours	96	-	-	-	-
Pressure (tolerance ±0.07 MPa)	MPa	2.1	-	-	-	-
Tensile strength, variation, max	percent	2.5	-	-	-	-
Elongation at break, variation, max	percent	3.5	-	-	-	-
Oil Resistance						
Treatment						
Oil temperature (tolerance ±2°C)	°C	-	-	-	100	-
Duration	hours	-	-	-	24	-
Tensile strength, variation, max	percent	-	-	-	±40	-
Elongation at break, variation, max	percent	-	-	-	±40	-
Hot Set						
Treatment						
Temperature (tolerance ± 3°C)	°C	-	250	250	200	-
Mechanical stress	N/cm^2	-	20	20	20	-
Hot set elongation, max	percent	-	175	175	175	-
Permanent set, max	percent	-	15	15	15	-

Table 2.12 Elastomeric Sheath Properties

(Table 3 under Clause 1.2 of IS 6380)

Property	Unit	SE1	SE2	SE3	SE4	SE5
Without ageing						
Tensile strength, min	N/mm^2	7.0	14.0	80.0	11.0	20.0
Tensile stress at 200 percent elongation, min	N/mm^2	-	-	-	4.0	-
Elongation at break, min	percent	300	300	250	250	150
After ageing in air oven						
Treatment						
Temperature (tolerance ±2°C)	°C	70	70	-	-	200
Duration	days	10	10	-	-	10
Tensile strength, variation, max	percent	±20	±20	-	-	±20
Elongation at break, variation, max	percent	±20	±20	-	-	±20
After ageing in air bomb						
Temperature (tolerance ±1°C)	°C	-	-	127	127	-
Duration	hours	-	-	40	40	-
Pressure (tolerance ± 0.02 MPa)	MPa	-	-	0.55	0.55	-
Tensile strength variation, max	percent	-	-	±50	±50	-
Elongation at break, variation, max	percent	-	-	±50	±50	-
Oil Resistance						
Treatment						
Oil temperature (tolerance ±2°C)	°C	-	-	100	100	-
Duration	hours	-	-	24	24	-
Tensile strength, variation, max	percent	-	-	±40	±40	-
Elongation at break, variation, max	percent	-	-	±40	±40	-
Tear Resistance, min	N/mm	-	5.0	-	5.0	-
Hot Set						
Treatment						
Temperature	°C	-	-	200	200	-
Mechanical stress	N/cm^2	-	-	20	20	-
Hot set elongation, max	percent	-	-	175	175	-
Permanent set, max	percent	-	-	15	15	-

(c) PE Compound

Some important properties of PE Insulation are given in Table 2.13.

Table 2.13 PE Insulation Properties

(Table 2 under Clause 5.1 of IS 14255)

Property	Requirement
Tensile Strength, min	10 N/mm^2
Elongation at break, min	300 percent
Volume resistivity	
at 27°C, min	1×10^{14} ohm-cm
at 90°C, min	1×10^{12} ohm-cm
Melt Flow Index, max	3
Vicat softening point, min	85ºC
Environmental stress cracking	No cracks shall be visible to naked eye

(d) XLPE Compound

Polyethylene is used as one of the important insulations for cable, but, has limited applications due to thermal constraints. Cross linking increases thermal properties of the base polymer and gives improved stability at higher temperatures when compared to thermoplastic materials. Some important properties of XLPE Insulation are given in Table 2.14.

Table 2.14 XLPE Insulation Properties

(Table 1 under Clause 5.1 of IS 14255, Table 1 under Clause 4.1 of IS 7098-1, Table 1 under Clause 5 of IS 7098-2, Table 2 under Clause 5 of IS 7098-3)

Property	**Requirement**
Tensile Strength, min	12.5 N/mm^2
Elongation at break, min	200 percent
After ageing in air oven	
Treatment	
Temperature	135± 3°C
Duration	7 days
Tensile Strength, variation, max	± 25 percent
Elongation, variation, max	± 25 percent
Hot set	
Treatment	
Test temperature	200±3°C
Time under load	15 minutes
Mechanical stress	20N/cm^2
Elongation under load, max	175 percent
Permanent elongation (set) after cooling, max	15 percent
Shrinkage	
Treatment	
Temperature	130 ± 3°C)
Duration	1 hour
Shrinkage, max	4 percent
Water absorption test (Gravimetric)	
Treatment	
Temperature	85± 2°C
Duration	14 days
Water absorbed, max	1 mg/cm^2
Volume resistivity	
at 27°C, min	1×10^{14} ohm-cm
at 90°C, min	1×10^{19} ohm-cm

2.3 Tests on Insulation and Sheath

2.3.1 Tensile Strength and Elongation before and after ageing

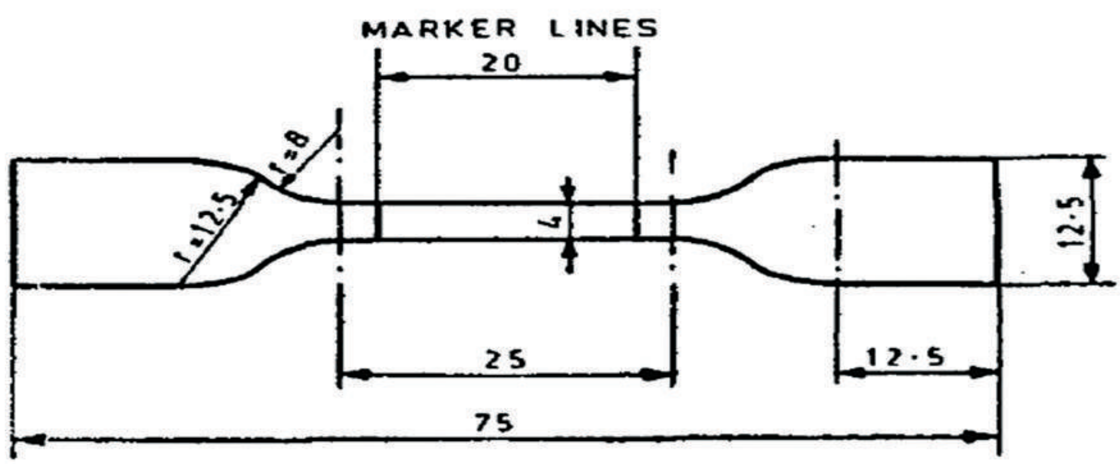
The following Indian Standard details the procedure for Tensile Strength and Elongation:

IS 10810 (Part 7) 'Methods of Test for Cables - Tensile Strength and Elongation at Break of Thermoplastic and Elastomeric Insulation and Sheath'

The method for determining the tensile strength and elongation at break of thermoplastic and elastomeric insulation and sheath of cables is explained in various clauses as given below:

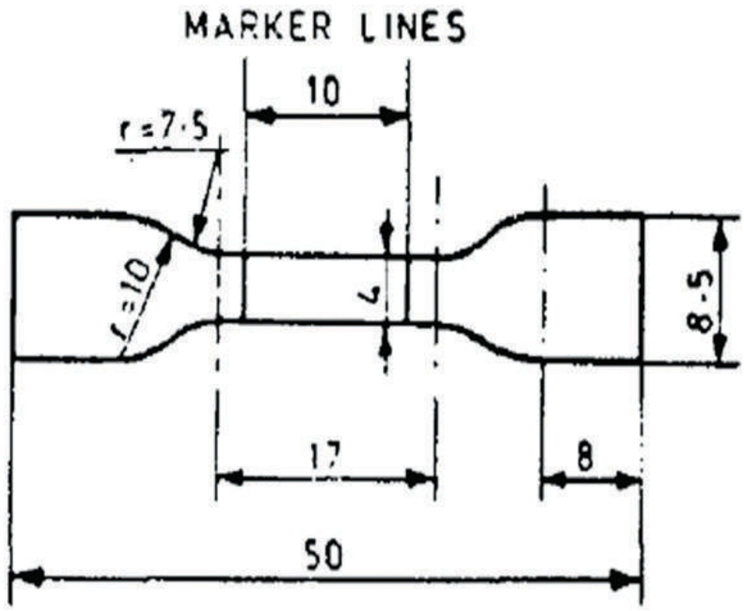
- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The test equipment consists of an automatic tensile testing machine, the rate of separation of jaws shall be not less than 250 ± 50mm/min. The test specimen may be dumb-bell or tubular shape, cut out lengthwise from insulation /sheath. Tubular test specimens shall be used only when insulated conductor/sheathed cable is of such a small size that it is not possible to prepare dumb-bell test pieces from them. The shape and dimensions of dumb-bell punching die for preparing dumb-bell test specimens are as shown in Fig. 2.1 and Fig. 2.2.



All dimensions are in mm

Fig. 2.1 Standard dumb-bell test piece



All dimensions are in mm

Fig. 2.2 Small dumb-bell test piece

The cross-sectional area of test specimen is determined by dimensional measurement or by computation from density, mass and length measurement. All test specimens are conditioned at a temperature of 27 ± 2°C for a period of not less than 3 hours prior to testing. The gauge length is marked on specimen by two lines centrally. The gauge length is taken as 20 mm for tubular specimen and dumb-bell specimen. For small dumb-bell specimen, gauge length is taken as 10 mm.

The tensile strength and elongation at break are determined simultaneously on same test specimen. During the test, distance between marker lines shall be closely followed and elongation shall be determined by measuring distance between two marker lines at the instant of break, that is, the separation of gauge marks at break. This distance is used to calculate percentage elongation at break based on the original gauge length. The breaking load at which test specimen breaks is also recorded for each test piece.

Area of tubular test specimen $A = \pi (D-t)t$ *or* $A = 1000\ m / (s \times l)$

Area of dumb bell test specimen $A = W \times t$ *or* $A = 1000\ m / (s \times l)$

Tensile strength= F/A

Elongation at break, percent = $[(G_2 - G_1) / G_1] \times 100$

where,

A is the area of the specimen in mm^2,

D is the mean value of outer diameter of tubular test specimen in mm,

t is the mean value of thickness of test specimen in mm,

m is the mass of relevant length of test specimen in g,

s is the density of material in g/cm^3,

l is the relevant length of test specimen in mm, W is the mean value of width of dumb-bell test specimen within gauge length in mm,

F is the Load at break in N/mm^2

G_1 is the original gauge length in mm

G_2 is the separation of gauge marks at break in mm

The tensile strength and elongation at break shall meet the requirements as specified.

Significance

During the process of manufacture and during installation, electric cables are unavoidably subjected to mechanical stresses, particularly bending. Thermoplastic or elastomeric insulation and/or sheath in the cable are also subjected to these stresses and strains. The tensile test result establishes whether the insulation and/or sheath have requisite tensile strength and elongation to withstand the stresses. The test for cable tensile strength and cable elongation is performed on materials in the condition as manufactured, but subsequent testing after accelerated ageing is also required for these material types. Results after ageing give an appreciation of how ageing affects the mechanical properties of the materials.

2.3.2 Volume Resistivity and Insulation Resistance Constant

The following Indian Standard details the procedure for measurement of Volume Resistivity and Insulation Resistance Constant:

IS 10810 (Part 43) 'Method of Tests for Cables – Insulation Resistance'.

The method for determining insulation resistance, calculation of volume resistivity and insulation resistance constant of the dielectric material of electric cables is given in detail in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The insulation resistance is measured using Megohmmeter. The test is performed at ambient temperature and at elevated temperature, wherever specified. The test specimen consists of full drum length of cable or minimum 3 meters.

For carrying out the test at ambient temperature (27 ± 2°C) on single core armoured/ screened and multicore screened (armoured or unarmoured), no special conditioning is required except that it shall be ensured that test specimen has attained the temperature of test room. For belted multicore cables (armoured or unarmoured) and single core cables (unscreened and unarmoured) this test is performed by taking out insulated cores from finished cable (removing outer sheath, armour etc.) and immersing them in water maintained at 27 ± 2°C. The duration of immersion shall be 12 h for elastomer insulated cores and one hour for all other types of cores. For carrying out this test at elevated temperature in case of all types of cables, insulated cores are taken out from finished cable (by removing outer sheath, armour and screen) and immersed in water, the temperature of which is maintained as specified. During immersion, ends of cores shall project approximately 200mm above water in water bath. The duration of immersion is one hour.

The test specimen is connected to insulation resistance measuring equipment. The conductor is connected to high voltage terminal and screen/armour or water bath is earthed. The insulation resistance of test specimen is measured after electrification has continued in a regular manner for 1 min. When the test is performed at ambient temperature, the ambient temperature is recorded. But, while performing the test at elevated temperature, the temperature of water bath is recorded.

The volume resistivity or the insulation resistance constant is calculated from the measured insulation resistance value.

$$\text{Volume Resistivity} = \frac{2\pi LR \times 10^{8}}{\log_e \frac{D}{d}} \ \Omega \ \text{cm}$$

$$\text{Insulation Resistance Constant } K = \frac{L\,R}{1000 \log_{10} \frac{D}{d}} \ \text{M}\Omega \ \text{km}$$

where,

R = Measured Resistance (M Ω), L = length of cable(m)

D = diameter over insulation (excluding screens, if any) in mm

d = diameter over conductor (including screens, if any) in mm

Significance

The insulating materials in a cable are used to insulate conductors from one another and from earth as well as to provide mechanical support for components. For these purposes it is generally desirable to have insulation resistance as high as possible, consistent with acceptable chemical, mechanical and heat resisting properties. During the manufacturing process, non-uniformities may develop in the dielectric either in the form of conductive impurities in material or in the form of mechanical imperfections in dielectric affecting the quality of cable. Volume resistivity measurements are often used in checking the uniformity of an insulating material, either with regard to processing or to detect conductive impurities that affect the quality of the material and that may not be readily detectable by other means. Thus, this test is helpful in detecting these imperfections.

2.3.3 Loss of Mass

The following Indian Standard details the procedure for Loss of Mass test:

IS 10810 (Part 10) 'Methods of Test for Cables – Loss of Mass Test'

The method for determining the thermal effect on the mass of thermoplastic insulation and sheath is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The test equipment consists of thermostatically controlled electric oven with controlled air flow, weighing balance of least count of 0.2 mg and suitable tube of approximate 100 mm dia and 300 mm length. The air shall enter the oven in such a way that it flows over the surface of test piece and leaves near top of oven. The oven shall have a rate of air flow ensuring 8 to 20 changes per hour at specified ageing temperature.

The test specimen consists of dumb bell piece having two parallel surfaces and thickness of 1.0 ± 0.2 mm or tubular test specimen, the total surface area of each specimen not less than5cm^2. Three test specimens are used in measurement.

The surface area of each test specimen is determined as given below:

a) *For tubular specimen*

Surface area A = Outer surface + Inner surface + Cut surface

$$A = \frac{2\pi\,(D-t) \times (L+t)}{100}\ \text{cm}^2\text{, where,}$$

t = mean value of thickness of test specimen, in mm

D = mean value of outer diameter of test pieces, in mm

L = length of test specimens in mm

b) *For standard dumb bell test specimen*

$$A = \frac{1256+(180t)}{100}\ \text{cm}^2$$

c) *For smaller dumb bell test specimen*

$$A = \frac{624+(118t)}{100}\ \text{cm}^2$$

where, 't' is the mean thickness of the strips, in mm

Each test specimen is weighed accurately, in milligrams and is then suspended in the tube. Each specimen shall be atleast 20 mm away from any other specimen and from wall of the tube. No other test specimen of different compound shall be exposed in the tube at the same time. The tube is then suspended vertically in oven at a temperature and duration as specified. After this heat treatment, the specimen is cooled to room temperature and weighed again.

Loss of mass of the specimen (in mg/cm^2) = $(W_1 - W_2)/A$, where,

W_1 = Mass before ageing, in mg

W_2 = Mass after ageing, in mg

The median value of the results from each core shall be taken as the loss of mass.

Significance

Loss of mass test is a method to determine the thermal effect on the mass of thermoplastic insulation and sheath. Thermoplastic insulation and sheath exposed to heat are subjected to many types of physical and chemical changes. The severity of exposures, in both time and temperature, determines the extent and type of change that takes place. Extended periods of exposure of insulation and sheath to elevated temperatures will generally cause some degradation with progressive changes. By measuring loss of mass on subjecting the material to accelerated ageing, these changes are assessed and the results give an indication of the extent of degradation that has happened to insulation and sheath.

2.3.4 Hot Deformation

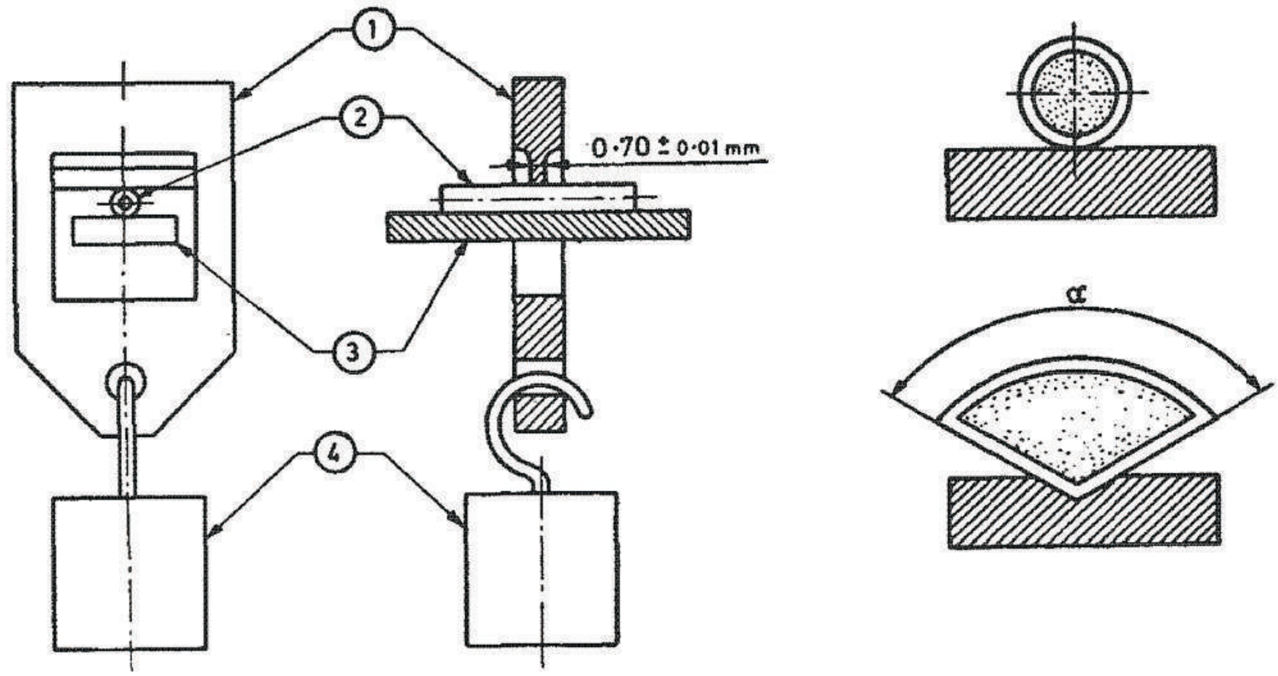
The following Indian Standard details the procedure for Hot Deformation test:

IS 10810 (Part 15) 'Methods of Tests for Cables – Hot Deformation Test'

The method for determining the resistance of thermoplastic insulation and sheath of electric cables to deformation when subjected to mechanical pressure at high temperature is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The test equipment consists of 'Hot pressure test apparatus', as shown in Fig. 2.3, which is used to exert pressure on test specimen. It has a rectangular blade with an edge of 0.70 ± 0.01 mm wide which can be pressed against test specimen and loading weights.



1 = Testing Frame 2 = Sample 3 = Supports 4 = Load α = Sector angle

Fig. 2.3 Hot Pressure Test Apparatus

A thermostatically controlled electric oven is also used in the test, in which test temperature can be maintained with an accuracy of ±2°C and is mounted in such a manner as to be free from vibration. The force F, in Newton, which shall be exerted by the blade upon the test specimen, is calculated by the following formula:

$F = k, \sqrt{2D \times t - t^2}$, where

D = mean value of the outer diameter (mm) of test piece (insulation or sheath).

t = average thickness (mm) of the test specimen (insulation or sheath)

k = a constant, the value of which is as follows:

k = 0.6 for insulation and sheath of flexible cords and flexible cables;

k = 0.6 for cables for fixed installations having outer diameter (D) of core or sheath up to10 mm; and

k = 0.8 for cables for fixed installations having outer diameter (D) of core or sheath above10 mm.

For the above purpose, D and t shall be measured to an accuracy of 0.1 mm using any suitable mechanical or optical measuring instrument. The calculated force may be rounded off downwards by not more than 3 percent. However, in all cases, the load or force indicated include weight of the testing frame.

When test oven attains specified test temperature, the loaded test specimen is kept in oven for the duration as specified. At the end of test duration, test specimen is removed from testing apparatus and cooled within 10 s in cold water. Immediately after cooling, test specimen is prepared for determining the indentation i.e. thickness retained at the point of impression. The thickness at the point of impression, in mm (T_1) and at a distance of about 10mm on both sides of this point, in mm $(T^1_2$ and $T^{11}_2)$ is measured by means of measuring microscope to an accuracy of 0.01 mm as shown in Fig. 2.4.

$$\text{Percentage thickness retained} = \frac{(\Sigma T_1)/2}{T_2} \times 100$$

$$T2 = \frac{\Sigma T^1_2 + \Sigma T^{11}_2}{4}$$

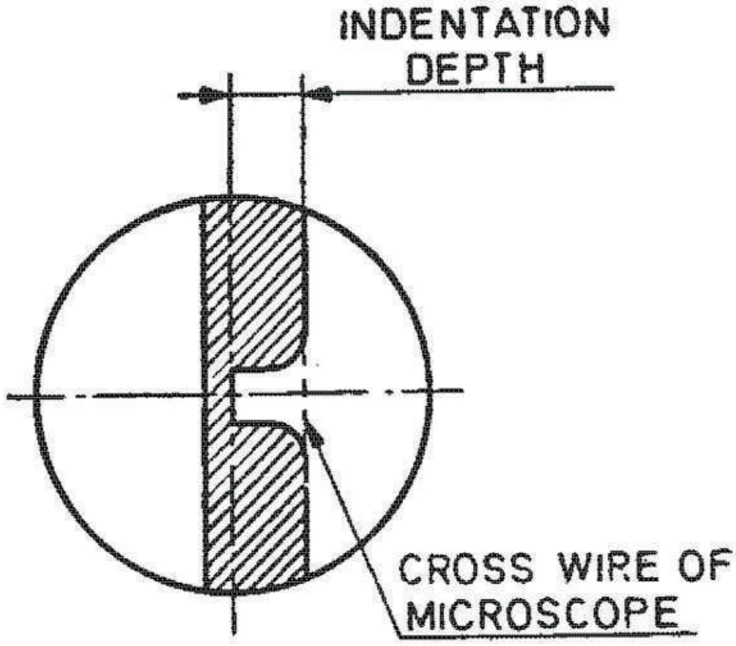


Fig. 2.4 View in measuring microscope

Significance

'Hot deformation' is the change in physical dimension of a solid material when subjected to external mechanical pressure at high temperature. Hot deformation test is a method to determine the resistance of thermoplastic insulation and sheath of electric cables to deformation when subjected to mechanical pressure at high temperature. In hot deformation test, thickness retained at the point of impression expressed as a percentage of initial thickness denotes the degree of resistance of the material to hot deformation.

Thermoplastic compounds tend to soften when maintained at high temperature over a sufficient period. In that condition when they are subjected to mechanical pressure, they tend to get deformed at the location of pressure resulting in reduction in thickness. Thermoplastic insulation and sheath of electric cables are subjected to such conditions while they are in continuous operation and undue deformation will impair their functional utility. Hot deformation test is therefore carried out to check whether the insulation and sheath have sufficient resistance to such deformation.

2.3.5 Heat Shock

The following Indian Standard details the procedure for Heat Shock test:

IS 10810 (Part 14) 'Heat Shock Test'

The method for determining cracking of thermoplastic insulation and sheath of electric cables taking place on overheating is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The test equipment consists of a thermostatically controlled electric oven with natural replacement of air. The core sample is taken from cable after first removing at least 300 mm length of cable from the end. The test specimens are prepared by winding test piece for three turns in a close helix round a circular mandrel as specified. Two test specimens are used in measurement. The test specimen assemblies are then placed in oven which has been set at the temperature as specified for required duration. At the end of test period, test specimens are removed from oven and allowed to cool in air for one hour. The test specimen which is still on the mandrel is examined for any crack visible to normal unaided eye.

The insulation and sheath are regarded as satisfactory if no cracks are observed.

> ***Significance***
>
> ***During service, a cable is likely to get overheated either due to overloading or due to short-circuit occurring in the system. This leads to degradation of insulation and reduces cable life. However, this is a long-term effect. But if such overheating causes cracking of insulation, it may possibly lead to immediate failure of cable. Through Heat Shock test, heat treatment is given to thermoplastic insulation and sheath at specified accelerated temperature and duration to ascertain it's withstandability at that condition. This test forms the basis for finding out cracking of thermoplastic insulation and sheath of electric cables taking place on overheating. Thus by performing Heat Shock test, behaviour of insulation and sheath under such conditions is observed and the tendency to crack due to overheating is assessed.***

2.3.6 Shrinkage Test

The following Indian Standard details the procedure for Shrinkage test:

IS 10810 (Part 12) 'Shrinkage Test'.

The method for determining shrinkage characteristics of thermoplastic insulation and sheath of electric cables after exposure to specified elevated temperature is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The test equipment consists of a thermostatically controlled electric oven with natural replacement of air. A sample of cable about 220 mm in length is taken. In case of test on insulation, specimen shall be stripped of all coverings over insulation. The insulation or sheath shall then be cut down to a length of 200 mm measured with an accuracy of 0.5 mm. The test specimen is then kept in air oven horizontally, at temperatures and duration as specified. After this period, the specimen is taken out of the oven, and cooled down in air to 27 ± 2°C. The longitude shrinkage of insulation or sheath is measured with an accuracy of 0.5 mm. The specimen is also examined visually for any cracks.

Percentage shrinkage = $(L_1 - L_2) / L_1 \times 100$, where,

L_1 is the length of specimen before shrinkage, and

L_2 is the length of specimen after shrinkage.

> ***Significance***
>
> ***Shrinkage test covers determination of shrinkage characteristics of thermoplastic insulation and sheath of electric cables after exposure to specified elevated temperature. The extruded polymeric materials may have residual strain which is relieved on heating causing shrinkage. Shrinkage is defined as decrease in original length of test specimen after heat treatment, expressed as percentage of original length of test specimen. The purpose of this test is to determine such shrinkages so that this may not cause any problem in terminations when cable gets heated due to energization.***

2.4 Types of Cables

There are different types of cables for use in various applications depending upon the specific purpose. Some of the important cables in this category are listed below:

2.4.1 PVC Insulated Cables

PVC insulated cables are used in electric power and lighting including outdoor and low temperature use. BIS has published the following Indian Standards for PVC insulated cables of a wide range of types:

(a) IS 694 'Polyvinyl Chloride (PVC) Insulated Unsheathed and Sheathed Cables/ Cords with Rigid and Flexible Conductor for Rated Voltages up to and including 450/750 V'.

The requirements of single and multicore cables/cords with rigid as well as flexible annealed bare/tinned copper and aluminium conductor, insulated and sheathed (if any) with PVC for rated voltages up to and including 450/750 V ac, 50 Hz are detailed in this Standard.

These cables may also be used on dc systems for rated voltages up to and including 1500 V to earth. Cables with fire performance category in FR (Flame Retardant) and category FR-LSH (Flame Retardant Low Smoke and Halogen) with conductor temperature not exceeding 70°C or 85°C also are covered in the Standard, and are required to qualify and comply with the additional requirements as specified for these special categories of cables.

The Standard has following three sections:

Section I - General Requirements

- *Conductor - Clause 4*
- *Insulation - Clause 5*
- *Sheath - Clause 8*
- *Tests - Clause 10*

Section II - Single core cables/ cords for fixed and flexible wiring

Section III - Sheathed single and multicore cables/cords for fixed and flexible wiring

(b) IS 17048 'Halogen free flame retardant (HFFR) cables for working voltages up to and including 1100 Volts'

The general requirements of single and multicore cables/cords with rigid as well as flexible annealed bare/tinned copper and aluminium conductor insulated and sheathed (if any) with thermoplastic or cross-linked Halogen Free Flame Retardant (HFFR) material for voltages up to and including 1100 V a.c., 50 Hz, used in power and lighting installations including cables for low temperature applications are covered in this Standard.

These cables may also be used on d.c. systems for rated voltages up to and including 1500 V to earth. These cables are suitable to use for conductor temperature not exceeding 70°C for thermoplastic or 90°C for cross-linked material.

The Standard has following three sections:

Section I - General Requirements

- *Material - Clause 4*
- *Tests - Clause 10*

Section II ***- Unsheathed single core cables/ cords for fixed and flexible wiring***

Section III ***- Sheathed single and multicore cables/cords for fixed and flexible wiring***

(c) IS 17505 (Part 1) 'Thermosetting Insulated Fire Survival Cables for fixed installation having low emission of smoke and corrosive gases when affected by fire for working Voltages up to and including 1100 V AC and 1500 V DC - Requirements for Armoured Cables'.

The requirements of thermosetting insulated armoured fire survival cables for fixed installations having low emission of smoke and corrosive gasses for maintaining circuit integrity when affected by fire for single phase and three phase systems, suitable for operation at voltages up to and including 1 100 V a.c. and 1 500 V d.c. are covered in this Standard.

These cables are suitable for use where combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding 90 °C under normal operation and 250 °C under short circuit conditions.

The Standard has following five sections:

Section I ***- General***

Section II ***- Materials***

- *Conductor - Clause 4*
- *Insulation - Clause 6*
- *Inner Sheath - Clause 7*
- *Armour - Clause 8*
- *Outer Sheath - Clause 9*

Section III ***- Construction***

Section IV ***- Tests***

Section V ***- Identification, Packing and Marking***

2.4.2 PVC Insulated (Heavy Duty) Cables

PVC insulated cables are also designed to meet heavy duty applications.BIS has published the following Indian Standards for Heavy Duty PVC insulated cables of a wide range of types:

(a) IS 1554 (Part 1) 'PVC Insulated (Heavy Duty) Electric Cables for working voltages up to and including 1100 V'

The requirements of armoured and unarmoured single core, twin-core, three-core and multi-core PVC insulated and sheathed cables for electric supply and control purposes are covered in this Standard.

These cables are suitable for use on a.c. single phase or three phase (earthed or unearthed) systems for rated voltages up to and including 1100 V. These cables may also be used on d.c. systems for rated voltages up to and including 1500 V to earth.

These cables are suitable for use where the combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding the following:

Type of Insulation	*Normal Continuous Operation*	*Short Circuit Condition*
General purpose	*70°C*	*160°C*
Heat resisting	*85°C*	*160°C*

Armoured cables specified in this Standard are suitable for use in mines also. However, for such cables, additional requirements have to be complied with, as specified.

The Standard has following five sections:

Section I - General

Section II - Materials

- *Conductor - Clause 3*
- *Insulation - Clause 4*
- *Inner Sheath - Clause 5*
- *Armour - Clause 6*
- *Outer Sheath - Clause 7*

Section III - Construction

Section IV - Tests

Section V - Identification, Packing and Marking

(b) IS 1554 (Part 2) 'PVC Insulated (Heavy Duty) Electric Cables for working voltages from 3.3 kV up to and including 11 kV'

The requirements of the following categories of PVC insulated and sheathed power cables for electricity supply purposes are covered in this Standard.

i) Single-core unscreened, unarmoured (but non-magnetic metallic tape covered)

ii) Single-core screened, unarmoured

iii) Single-core armoured (non-magnetic), screened or unscreened

iv) Three-core armoured, screened or unscreened

These cables may be operated continuously at a power frequency voltage up to 10 percent higher than the rated voltage and are suitable for use where combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding 70°C under normal operation and 160°C under short-circuit conditions. Heavy duty armoured cables specified in this Standard are suitable for use in mines also. However, for such cables, additional requirements have to be complied with, as specified.

The Standard has following five sections:

Section I - General

Section II - Materials

- *Conductor - Clause 3*
- *Insulation - Clause 4*
- *Inner Sheath - Clause 6*
- *Armour - Clause 7*
- *Outer Sheath - Clause 8*

Section III - Construction

Section IV - Tests

Section V - Identification, Packing and Marking

2.4.3 XLPE Cables

XLPE cables are used in electric supply systems due to its excellent electrical, mechanical and heat resistance properties. BIS has published the following Indian Standards for XLPE cables of a wide range of types:

(a) IS 7098 (Part 1) 'Cross linked Polyethylene Insulated PVC Sheathed Cables for working voltages up to and including 1100 V'

This Indian Standard covers the requirements for armoured and unarmoured single, twin, three, four and multi-core cross-linked polyethylene (XLPE) insulated and PVC sheathed cables for electric supply and control purposes.

These cables are suitable for use on a.c. single phase or three phase (earthed or unearthed) systems for rated voltages up to and including 1100 V. These cables may be used on d.c. systems for rated voltages up to and including 1100 V to earth. These cables may be operated continuously at a power frequency voltage 10 percent higher than the rated voltage and are suitable for use where combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding 90°C under normal operation and 250°C under short-circuit conditions.

Armoured cables specified in this Standard are suitable for use in mines also. However, for such cables, additional requirements have to be complied with, as specified.

The Standard has following five sections:

Section I - General

Section II - Materials

- *Conductor - Clause 3*
- *Insulation - Clause 4*
- *Inner Sheath - Clause 5*
- *Armour - Clause 6*
- *Outer Sheath - Clause 7*

***Section III** - Construction*

***Section IV** - Tests*

***Section V** - Identification, Packing and Marking*

(b) IS 7098 (Part 2) 'Cross-linked Polyethylene Insulated PVC Sheathed Cables for working voltages from 3.3 kV up to and including 33 kV'

This Indian Standard covers the requirements of the following categories of cross-linked polyethylene insulated and PVC sheathed or polyethylene sheathed cables for single phase or three phase (earthed or unearthed) systems for electricity supply purposes:

i) Single-core unscreened, unarmoured (but non-magnetic metallic tape covered)

ii) Single-core screened, unarmoured

iii) Single-core armoured (non-magnetic), screened or unscreened

iv) Three-core armoured, screened or unscreened

These cables may be operated continuously at a power frequency voltage up to 10 percent higher than the rated voltage and are suitable for use where sum of ambient temperature and temperature rise due to load results in conductor temperature not exceeding 90°C under normal operation and 250°C under short-circuit conditions.

Armoured cables up to 11 kV grade specified in this Standard are suitable for use in mines also. However, for such cables, additional requirements have to be complied with, as specified.

The Standard has the following important clauses:

- *Conductor - Clause 4 & Clause 10*
- *Insulation - Clause 5 & Clause 12*
- *Inner Sheath - Clause 7 & Clause 16*
- *Armour - Clause 8 & Clause 17*
- *Outer Sheath - Clause 9 & Clause 18*
- *Tests - Clause 19 & Clause 20*
- *Identification - Clause 21*
- *Packing & Marking - Clause 22*

(c) IS 7098 (Part 3) 'Cross-linked Polyethylene Insulated PVC Sheathed Cables for working voltages from 66 kV up to and including 220 kV

This Indian Standard covers the requirements of single core, cross-linked polyethylene insulated, unarmoured or armoured (with or without lead alloy sheath) and thermoplastic outer sheathed cables for 3 phase ac earthed system for electric supply.

These cables are suitable for use where the combined ambient temperature and temperature rise due to load results in conductor temperature not exceeding 90°C under normal operation and 250°C under short circuit operation.

The Standard has following five sections:

Section I ***- General***

Section II ***- Materials***

- *Conductor - Clause 4*
- *Insulation - Clause 5*
- *Inner Sheath - Clause 8*
- *Armour - Clause 9*
- *Outer Sheath - Clause 10*

Section III ***- Construction***

Section IV ***- Tests***

Section V ***- Identification, Packing and Marking***

2.4.4 Elastomer Insulated Cables

Electrical cables with elastomer insulation are distinguished by a special kind of insulation composed of elastomeric compounds. Rubber-like materials called elastomers provide flexibility, toughness, and resistance to a range of environmental conditions. Elastomer insulated cables are used in electric power and lighting operation. BIS has published the following Indian Standards for Elastomer insulated cables of a wide range of types:

(a) IS 9968 (Part 1) 'Elastomer Insulated Cables for working voltages up to and including 1100 V'

This Indian Standard covers the requirements of cables for fixed wiring, flexible cables and flexible cords.

These cables are suitable for use on single-phase or three-phase (earthed or unearthed) systems, for rated voltages up to and including 1100 volts. These cables may be used on d.c. systems for rated voltages up to and including 1500 volts to earth. These cables are suitable for use where the combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding the following:

Type of Insulation	***Normal Continuous Operation***	***Short Circuit Condition***
General service	*60°C*	*200°C*
Heat resisting	*90°C*	*250°C*
Silicone rubber	*150 °C*	*350 °C*

The Standard has following five sections:

Section I ***- General***

Section II ***- Materials***

- *Conductor - Clause 3*
- *Insulation - Clause 4*
- *Sheath - Clause 8*

Section III ***- Construction***

Section IV ***- Tests***

Section V ***- Identification, Packing and Marking***

(b) IS 9968 (Part 2) 'Elastomer Insulated Cables for working voltages from 3.3 kV up to and including 33 kV'

This Indian Standard covers the requirements of heat resisting elastomer insulated cables for fixed installations and flexible cables.

These cables are suited for use on single-phase or three-phase systems, for working voltages from 3.3 kV up to and including 33 kV. These cables may be operated continuously at a power frequency voltage 10 percent higher than rated voltage.These cables are suitable for use where combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding 90°C under normal operation and 250°C under short circuit conditions.

The Standard has following five sections:

Section I ***- General***

Section II ***- Materials***

- *Conductor* *- Clause 4*
- *Insulation* *- Clause 5*
- *Armour* *- Clause 10*
- *Sheath* *- Clause 11*

Section III ***- Construction***

Section IV ***- Tests***

Section V ***- Identification, Packing and Marking***

(c) IS 16246 'Elastomer Insulated Cables with limited circuit integrity when affected by fire'

This Indian Standard covers the requirements of heat resisting elastomer insulated cables for fixed installations for single phase and three phase systems suitable for operation at voltages up to and including 1100 V, for maintaining limited circuit integrity when affected by fire.

These cables are suitable for use where combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding 90°C under normal operation and 250°C under short circuit conditions.

The Standard has following five sections:

Section I ***- General***

Section II ***- Materials***

- *Conductor* *- Clause 4*
- *Insulation* *- Clause 5*
- *Armour* *- Clause 8*
- *Sheath* *- Clause 9*

Section III ***- Construction***

Section IV ***- Tests***

Section V ***- Identification, Packing and Marking***

2.4.5 Aerial Bunched Cables

Aerial Bunched Cables are used in overhead power distribution. BIS has published the following Indian Standard Aerial Bunched Cables of a wide range of types:

IS 14255 'Aerial Bunched Cables for working voltages up to and including 1100 Volts'

This Indian Standard covers the requirements of polyethylene/ cross-linked polyethylene insulated cables with aluminium conductors twisted over a central bare/ insulated aluminium alloy messenger wire for use as overhead distribution feeders.

These cables are suitable for use on single phase and three phase a.c. (earthed or unearthed) systems for rated voltages up to and including 1100 V. These cables are suitable for use where the combination of ambient temperature and temperature rise due to load, including temperature on exposure to direct sunlight results in conductor temperature not exceeding the following:

Type of Insulation	***Normal Continuous Operation***	***Short Circuit Condition***
Polyethylene	*70°C*	*160°C*
XLPE	*85°C*	*160°C*

The Standard has following five sections:

Section I ***- General***

Section II ***- Materials***

- *Conductor* *- Clause 4*
- *Insulation* *- Clause 5*

Section III ***- Construction***

Section IV ***- Tests***

Section V ***- Identification, Packing and Marking***

2.4.6 Solar Cables

A solar cable is the interconnection cable used in photovoltaic (PV) power generation and forms an important part of the photovoltaic system. Solar cables interconnect solar panels and other electrical components of a PV system. BIS has published the following Indian Standard for Solar cables of a wide range of types:

IS 17293 'Electric Cables for Photovoltaic Systems for rated voltage 1500 V d.c.'

This Indian Standard covers the requirements of single core cables for use in photovoltaic (PV) systems for installation at the direct current (d.c.) side. These are suitable for outdoor long-term installations directly exposed to solar radiations. Since these cables are directly exposed to direct sun radiations, air humidity etc., stringent requirements are set for these cables. These requirements ensure that the cables are weather and UV resistant.

These cables are designed to operate at a normal continuous conductor temperature of 90°C. The permissible period of use at a maximum conductor temperature of 120°C is limited to 20000 hours.

The Standard has the following important clauses:

- *Conductor* - *Clause 4*
- *Insulation* - *Clause 5*
- *Sheath* - *Clause 6*
- *Tests* - *Clause 11*
- *Packing & Marking* - *Clause 12*

2.5 Tests on Cables

2.5.1 Thickness of Insulation and Sheath

The following Indian Standard details the procedure for measurement of thickness of insulation and sheath:

IS 10810 (Part 6) 'Methods of Tests for Cables – Thickness of Thermoplastic and Elastomeric Insulation and Sheath'

The method for verification of thickness of thermoplastic and elastomeric insulation and sheath of electric cables is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The thickness is measured using micrometer gauge or vernier callipers or measuring microscope. The test specimen may be of two types, core/cable piece and slice piece. Core/Cable piece is used only in case of round cores and outer sheath. All the coverings, if any, are removed from the core without damaging the insulation. Slice piece is used when measurements are to be done using optical method. For this purpose, materials inside and outside insulation/sheath under measurement are removed without damaging insulation/sheath. Then, a thin slice is cut along a plane perpendicular to the axis of the conductor/cable.

For core/cable piece, diameter over and below insulation/sheath is measured at three different points (at intervals not less than 75 mm) along the length of the specimen using a micrometer gauge or a vernier calliper. At each point, two measurements are made at right angle. The measured average diameter below the insulation/sheath shall be subtracted from the average of the six measurements of diameter above insulation/sheath and the difference is divided by two The resulting value is taken as the average radial thickness of the insulation/sheath.

Average thickness of insulation/sheath = $(D_0 - D_1)/2$, where,

D_0 = average of six readings of diameter over insulation/sheath

D_1 = average of six readings of diameter below insulation/sheath.

Where the visual examination of the specimen reveals eccentricity, optical method shall be used by taking a slice specimen. For slice specimen, the sliced section of the specimen is placed under a measuring microscope with the plane of the slice perpendicular to the optical axis. When the inner profile of the specimen is circular, six measurements shall be carried out radially as far as possible equally spaced around the circumference. The first measurement shall be made at the place where thickness appears to be minimum. The sliced sections are taken from the specimen at equidistant points so that at least eighteen individual measurements can be made. The average of eighteen measurements shall be calculated and the minimum thickness shall also be recorded.

> ***Significance***
>
> ***The thickness of insulation or sheath is specified on the basis of voltage stress and/or mechanical forces the covering is expected to withstand in service. The measurement of such thickness determines the limits of such dimension to ensure that the requirements of the specification are satisfactorily met.***

2.5.2 High Voltage Test

The following Indian Standard details the procedure for High Voltage test:

IS 10810 (Part 45) 'Methods of Tests for Cables – High Voltage Test'

The method for performing high voltage test on electric cables is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

During manufacturing process, online evaluation of insulating and sheathing materials for specific end uses and detection of defects is carried out using Spark tester. The conductor of the core or the conductor, metallic sheath screen or the armour is continuously earthed and the insulated conductor or cable is inserted into the electrode of spark tester. This end is then pulled and fixed to a winding drum. The required voltage as specified is maintained between test electrode and conductor of core or cable under test. The cable or the insulated conductor is wound through the electrode of the spark tester and the faults, if any, are recorded.

The test equipment consists of a high voltage source and a thermostatically controlled water bath. The test specimen is full drum length of the cable or 3 meters minimum cable length. For performing the test at ambient temperature for multi-core (armoured/unarmoured) and single core (armoured/screened) cable, no conditioning is required. For performing this test at ambient temperature on unarmoured/unscreened single core cables, it shall be immersed in water at the ambient temperature and the duration of immersion shall be as specified.

For performing the test at an elevated temperature, the sample shall be conditioned in water bath at the stated temperature and the duration of immersion shall be as specified. The high voltage source is connected to the conductor of the core under test. The cores not under test, screen and armour are connected to the earth terminal. The voltage is raised slowly to permit accurate reading of the measuring instruments, but not so slowly as to cause unnecessary prolongation of the stress near the test voltage. The rate of rise of voltage above 75 percent of the test voltage should be about 2 percent per second of this voltage. However, different rate of rise may also be used, but it should not exceed 2000 V/s. The test voltage is raised to the specified value and is maintained for the specified time. After the specified time, the voltage is rapidly decreased but the voltage is not interrupted suddenly to avoid the possibility of switching transients which may affect the subsequent test results.

During the test, breakdown of insulation is to be observed and the sample meets the requirements in case there is no breakdown.

> ***Significance***
>
> ***The insulation material in a cable is used to isolate the conductors from one another and from ground, as well as to provide the necessary mechanical strength. The fundamental, requirement of the insulation in an electric cable is that it withstands the voltage imposed on it in service. It is necessary that an evaluation of the condition of the insulation be made by imposing a higher voltage stress for a short duration. Evaluating the insulation is critical for establishing cable quality and safety and HV testing ensures that the safety is as per design and standards.***

2.5.3 Flammability Test

The following Indian Standard details the procedure for Flammability test:

IS 10810 (Part 53) 'Methods of Test for Cables – Flammability Test'

The method of test on electric cables under fire conditions is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5

- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The test apparatus consists of a three-sided metal screen test chamber, 1200 ± 25mm high, 300 ± 25mm wide and 450 ± 25 mm deep, with open front and closed top and bottom, and a non-metallic base. The chamber is provided with clamps approximately 25 mm wide and positioned so that the distance between the top of the bottom clamp and the bottom of the top clamp is 550 ± 25 mm. A gas burner having a nominal bore of 10 mm and regulated to give flame approximately 125 mm long, with an inner blue cone approximately 40 mm long shall be used as the source of heat for testing. For cable diameter up to and including 50 mm one gas burner is used and for cable diameter greater than 50 mm two gas burners are used. The arrangement of burners with the sample is shown in Fig. 2.5.

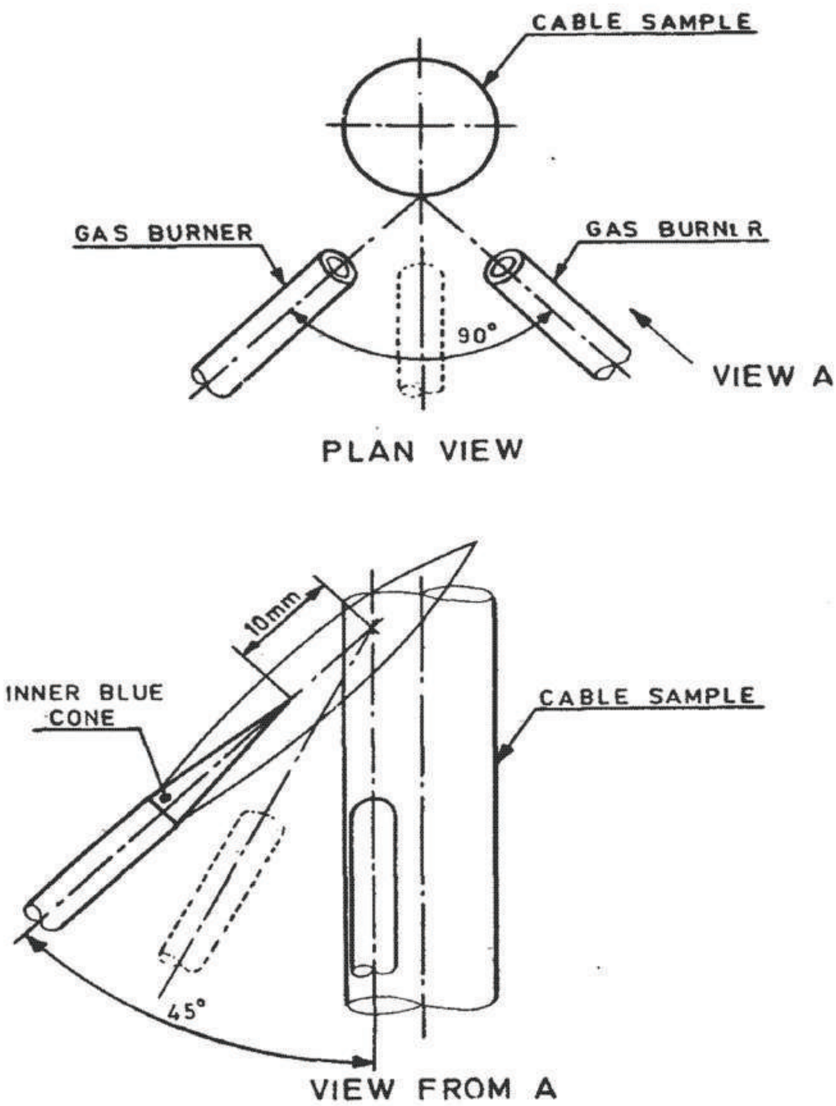


Fig. 2.5 Arrangement of burners for test

The test shall be made in an area substantially free from draughts. Draught shield may be fitted near the burner, if required. The gas burner is checked for satisfactory operation using bare copper wire 0.71 ± 0.025 mm in diameter, having a free length of not less than 100 mm and inserting it horizontally in the flame 50 mm above the top of the burner. The wire should melt within 4 to 6 seconds. The sample shall be clamped vertically and positioned in the middle of a three-sided metal screen. The cable shall be adjusted so that the bottom of the specimen is approximately 50 mm from the base of the screen. The arrangement is shown in Fig 2.6.

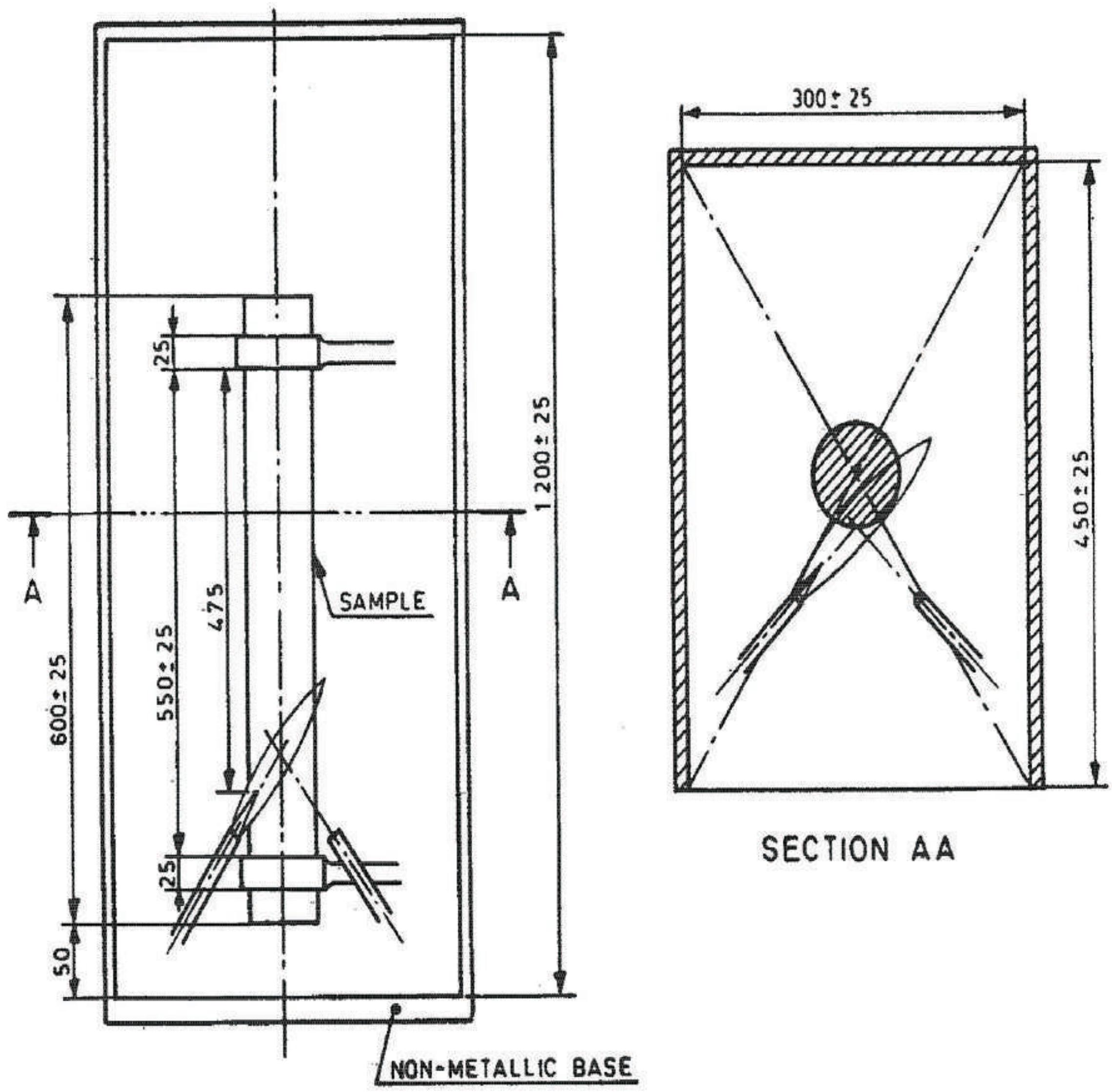


Fig. 2.6 Arrangement of sample within three-sided screen

The base of the burner should be at an angle of 45°C to the line of the sample. The distance of the burner from the sample shall be such that the inner blue cone of the flame is at a distance of approximately 10 mm, measured along the axis of the flame, from the surface of the cable and 475 mm below the lower edge of the top clamp. The flame is applied for a continuous period of T seconds, where, T = 60 + m/25, where,

m is the mass of cable sample in grams corrected to a 600 mm length.

After the burning has ceased, the distance between top of the charred or affected portion from the lower edge of top clamp is measured and shall meet the requirements as specified.

> ***Significance***
>
> ***Hazard from cables involved in a fire can take many forms, from the ease of ignition to flame propagation. A cable which retards flame in case of fire and is self-extinguishing when the source of fire is removed is important when it is used for certain locations. Flammability test is, therefore, carried out on finished cables to verify this property and to evaluate the potential performance of cables in case of fire.***

2.5.4 Oxygen Index Test

The following Indian Standard details the procedure for Oxygen Index test:

IS 10810 (Part 58) 'Method of Tests for Cables - Oxygen Index Test'

The detailed procedure for conducting the test is explained in various clauses as given below:

- Apparatus - Clause 5
- Test Specimen - Clause 6
- Procedure - Clause 7
- Tabulation of Observations - Clause 8
- Report - Clause 9

The principle of the method is that the minimum concentration of oxygen in a mixture of oxygen and nitrogen that will just support combustion is measured under equilibrium conditions of 'candle like' burning. The balance between the heat from the combustion of the specimen and the heat lost to surroundings establishes the equilibrium.

The apparatus used for measuring oxygen index consists of a heat resistant glass tube. The bottom of the column or the base to which the tube is attached is filled with glass beads, which is a non-combustible material that evenly distributes the gas mixture entering at this base. A wire screen shall be placed above the non-combustible material to catch falling fragments and aid in keeping the base of the column clean. A specimen holding device (clamp) is used to support the specimen at its base and hold it vertically in the center of the column. For physically self-supporting specimens, laboratory thermometer clamp inserted into the end of a glass tube held in place by glass beads or otherwise firmly supported is used. A typical arrangement is shown in Fig. 2.7. For other forms such as film, and thin sheet, the frame in Fig. 2.8 shall be used and held in place by the above tube. The test specimen must be held securely along both upright edges by the frame using clips or other means.

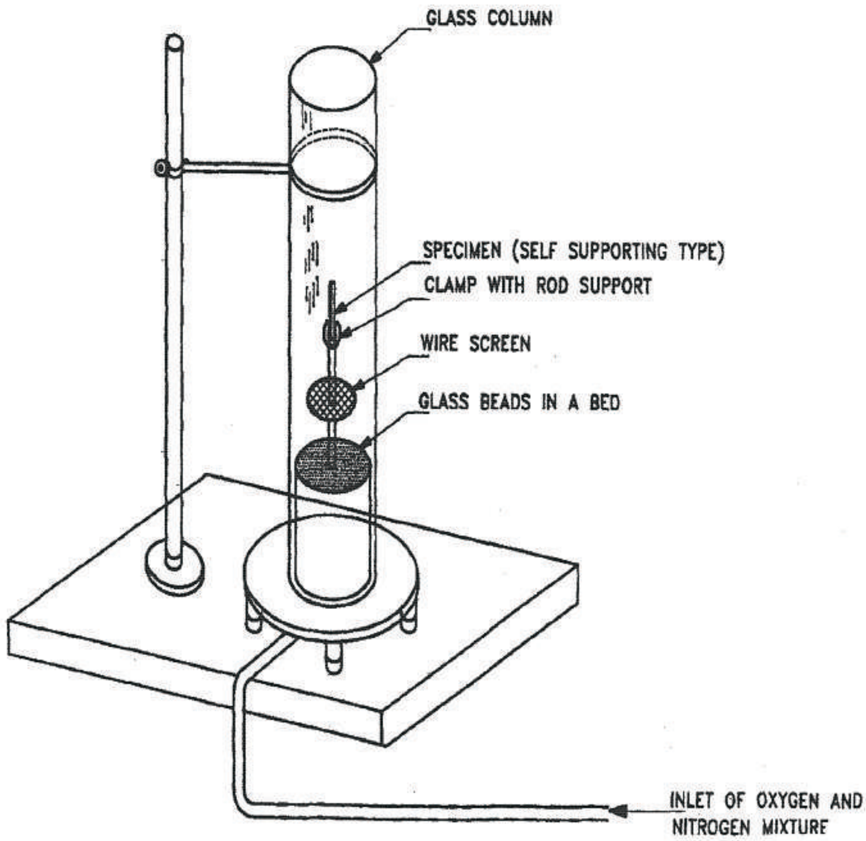
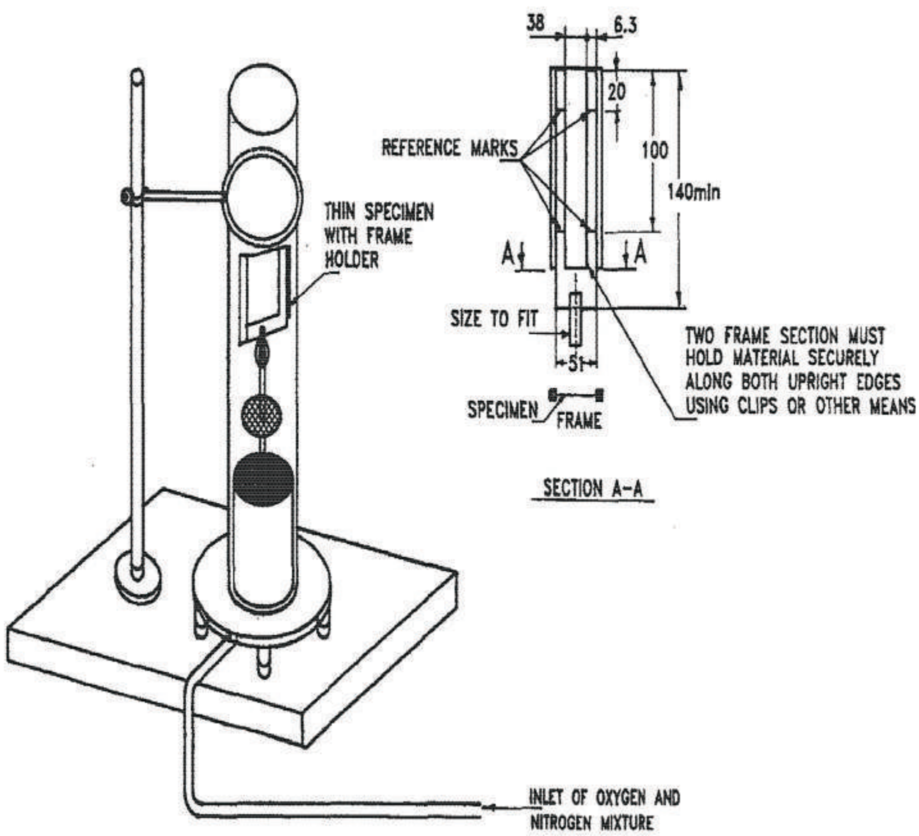


Fig. 2.7 Typical arrangement for oxygen index test



All dimensions are in mm

Fig. 2.8 Frame design and test arrangement for film and thin sheet

The gas mixture required for the test is prepared using oxygen and/or nitrogen of commercial grades or better (greater than 98 percent purity) and/or clean air as appropriate (air contains 20.9 percent oxygen). The igniter should be a suitable butane LPG gas torch.To ensure the removal of smoke, soot and toxic fumes the apparatus shall be installed in an area having excellent exhaust facilities that do not interfere with the test results.

Three test specimens shall consist of flat rectangular sheets having length 70 mm to 150 mm, width 6.5 ± 0.5 mm and thickness 3.0 ± 0.5 mm. The specimens may be obtained by moulding, cutting, or machining from the cable constituents to be tested. Where this is not possible with a cable containing vulcanized material, a moulded and vulcanized slab prepared from the material sampled during manufacture of the same production batch shall be used.

The specimen is clamped vertically in the holder in the center of the column. The test shall be carried out at room temperature. The flow valves are set to introduce desired concentration of oxygen into the column. The gas is allowed to flow for at least 30 seconds to purge the system.

The top of the specimen is ignited with the ignition flame and as the specimen burns, the ignition source is lowered to maintain the flame impingement. The oxygen concentration shall not be adjusted after lighting the test piece. The specimen is required to burn according to the specified criteria, which describes the time of burning or the length of specimen burnt. The test is repeated until the lowest concentration of oxygen which meets the specified criteria is obtained, which is taken as the approximate oxygen index. Conformity test is then carried out to determine the absolute oxygen index.

Significance

Oxygen index is the most widely used indicator of a material's flammability. It is the minimum concentration of oxygen, expressed as volume percent, in a mixture of oxygen and nitrogen that will just support combustion of material under specified conditions. The test method describes the procedure for determining the relative flammability of materials used in electric cables by measuring the oxygen index, which gives the indication of flame resistance propagation. Flame retardant materials require a level of oxygen higher than that normally present in the atmosphere (21%) for burning to be maintained. The higher the oxygen index, higher is the fire resistance and the material is considered to be self-extinguishing.

2.5.5 Temperature Index Test

The following Indian Standard details the procedure for Temperature Index test:

IS 10810 (Part 64) 'Methods of Test for Cables - Measurement of Temperature Index'

The detailed procedure for conducting the test is explained in various clauses as given below:

- Apparatus - Clause 5
- Test Specimen - Clause 6
- Procedure - Clause 7
- Tabulation of Observations - Clause 8
- Calculation - Clause 9
- Report - Clause 10

Temperature index of a material is the temperature in °C at which oxygen index of a material becomes 21 (the approximate percentage of oxygen in air) under the specified conditions.

The test apparatus is same as that used for oxygen index test. Three test specimens shall consist of flat rectangular sheets having length 70 mm to 150 mm, width 6.5 ± 0.5 mm and thickness 3.0 ± 0.5 mm. The specimens may be obtained by moulding, cutting, or machining from the cable constituents to be tested. Where this is not possible with a cable containing vulcanized material, a moulded and vulcanized slab prepared from the material sampled during manufacture of the same production batch shall be used.

A thermocouple is placed near the bottom to verify the pre-heating temperature and then it is placed near the top to determine the chimney temperature. Its position should be such as to avoid turbulence and shall not be subjected to heat from the burning specimen.

The ambient temperature is recorded and the gas flow in the chimney is adjusted to 4 ± 1cm/sec as calculated at standard temperature (0^{O}C) and pressure (101.3 kPa) from the total flow of gas in mm^3/sec divided by the area of the column in mm^2. When the temperature is stable, the specimen is clamped vertically at the centre of the column with the top of the specimen at least 100 mm below the top of the open column. The thermocouple is re-adjusted so as not to touch the specimen and is approximately 25 mm away from the centreline of the specimen. The thermocouple is removed after the temperature has re-established (usually within 10 min) and the oxygen index is determined at this temperature. Readings are taken at different temperatures by raising the temperature by 20^{O}C. The temperature index is determined by extrapolation of this data. The values of oxygen index against temperature are plotted using linear graph paper and the value of temperature at which the oxygen index is 21 is noted. The minimum temperature index is the temperature at which the oxygen index is 21 as observed from the graph.

Significance

Even though, Oxygen Index is the most widely used fire parameter in the assessment of materials, the burning of a material is significantly influenced by the actual temperature involved as the ease of ignition of materials is usually increased with increase in temperature. To address the effect of temperature, the Temperature Index test is widely used. The temperature index helps in assessment of the material properties under heat and fire. It explores the temperature at which the oxygen index of a material becomes 21.

2.5.6 Halogen Acid Gas Evolution

The following Indian Standard details the procedure for evaluation of Halogen Acid Gas evolution:

IS 10810 (Part 59) 'Methods of Test for Cables - Determination of the amount of Halogen Acid Gas evolved during combustion of polymeric materials taken from Cables'

The detailed procedure for conducting this test is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Method of determination - Clause 9
- Tabulation of Observations - Clause 10
- Calculation - Clause 11
- Report - Clause 12

Halogen Acid Gas Evolution test describes the method for determination of the amount of halogen acid gas other than hydrofluoric acid evolved during the combustion of compounds based on halogenated polymers and compounds containing halogenated additives, taken from cable insulation and outer sheath. Cable compound is heated up to maximum of 800°C and is decomposed completely. Halogen acid gas evolved during this is suitably collected and calculated in milligrams of hydrochloric acid per gram of sample taken.

The test specimen consists of a piece of sheath of cable cut into small piece or powdered. The test apparatus consists of a tube furnace, with thermostatic temperature control up to 1000°C. The specimen is accurately weighed (0.5 to 1 g), which is then inserted into the combustion tube placed in the tube furnace which is heated to 800^{O}C. Using this method, halogen acids evolved will be expressed as hydrochloric acid. The hydrochloric acid is absorbed into the water inside the chamber fed with air flow. The water is then tested with its acidity and the hydrochloric acid yield is measured. The test set up is shown in Fig. 2.9.

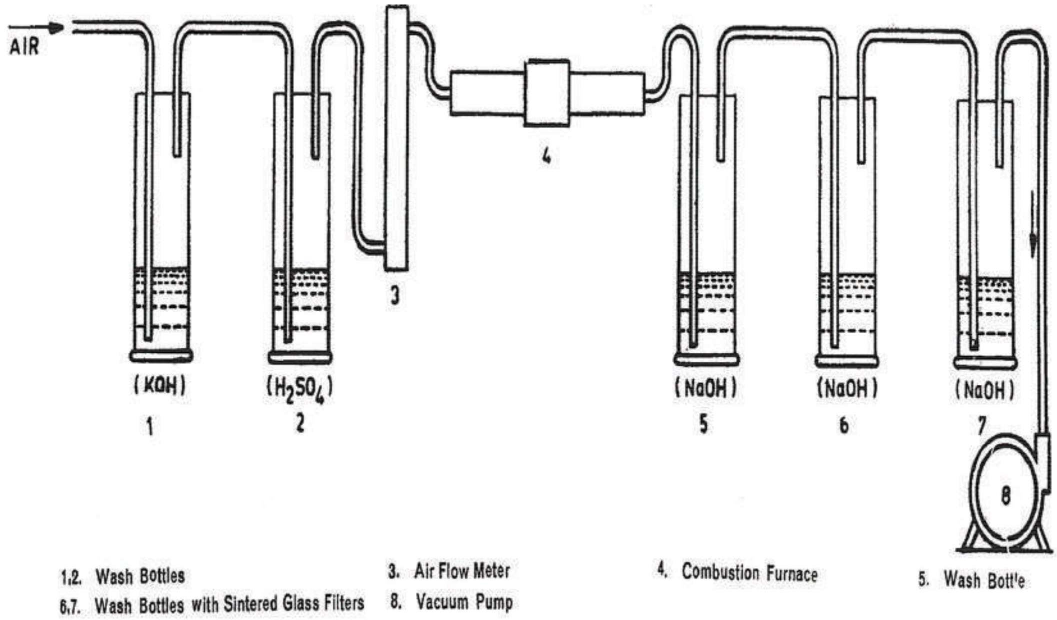


Fig. 2.9 Set up for halogen acid gas evolution test

Significance

During the combustion of compounds based on halogenated polymers and compounds containing halogenated additives, halogen acid is evolved. For certain locations, the amount of halogen acid gas evolved during burning of cables is very critical since this signifies the extent of corrosion that a compound is capable of causing in an environment. Halogen acid gas evolution test is, therefore, carried out on polymeric material components used in cable construction, to determine the amount of halogen acid gas evolved during combustion and is an index of corrosivity.

2.5.7 Smoke Density Test

The following Indian Standard details the procedure for Smoke Density test:

IS 10810 (Part 63) 'Method of Tests for Cables - Measurement of Smoke Density of Electric Cables under Fire Conditions'

The detailed procedure for conducting this test is explained in various clauses as given below:

- Apparatus - Clause 4
- Material for Testing - Clause 5
- Test Specimen - Clause 6
- Conditioning - Clause 7
- Procedure - Clause 8
- Tabulation of Observations - Clause 9
- Calculation - Clause 10
- Report - Clause 11

The equipment consists of a cubic enclosure with a door having a glass observation window. Transparent sealed windows are provided on two opposite sides to permit the transmission of a beam of light from the horizontal photometric system. The walls of the enclosure have orifices for the passage of cables and to permit the enclosure to be at atmospheric pressure. In order to ensure uniform distribution of the smoke, a table type fan is also placed on the floor of the enclosure. The cable piece to be tested is mounted on a frame placed above a vessel containing the ignition fluid (distilled alcohol). The fluid is ignited and allowed to burn until consumed. The test is completed when there is no change in light transmittance for 5 minutes after the source has extinguished. During the test period, the smoke density formation is measured.

The plan view of the test chamber is shown in Fig. 2.10 and the photometric system is illustrated in Fig. 2.11.

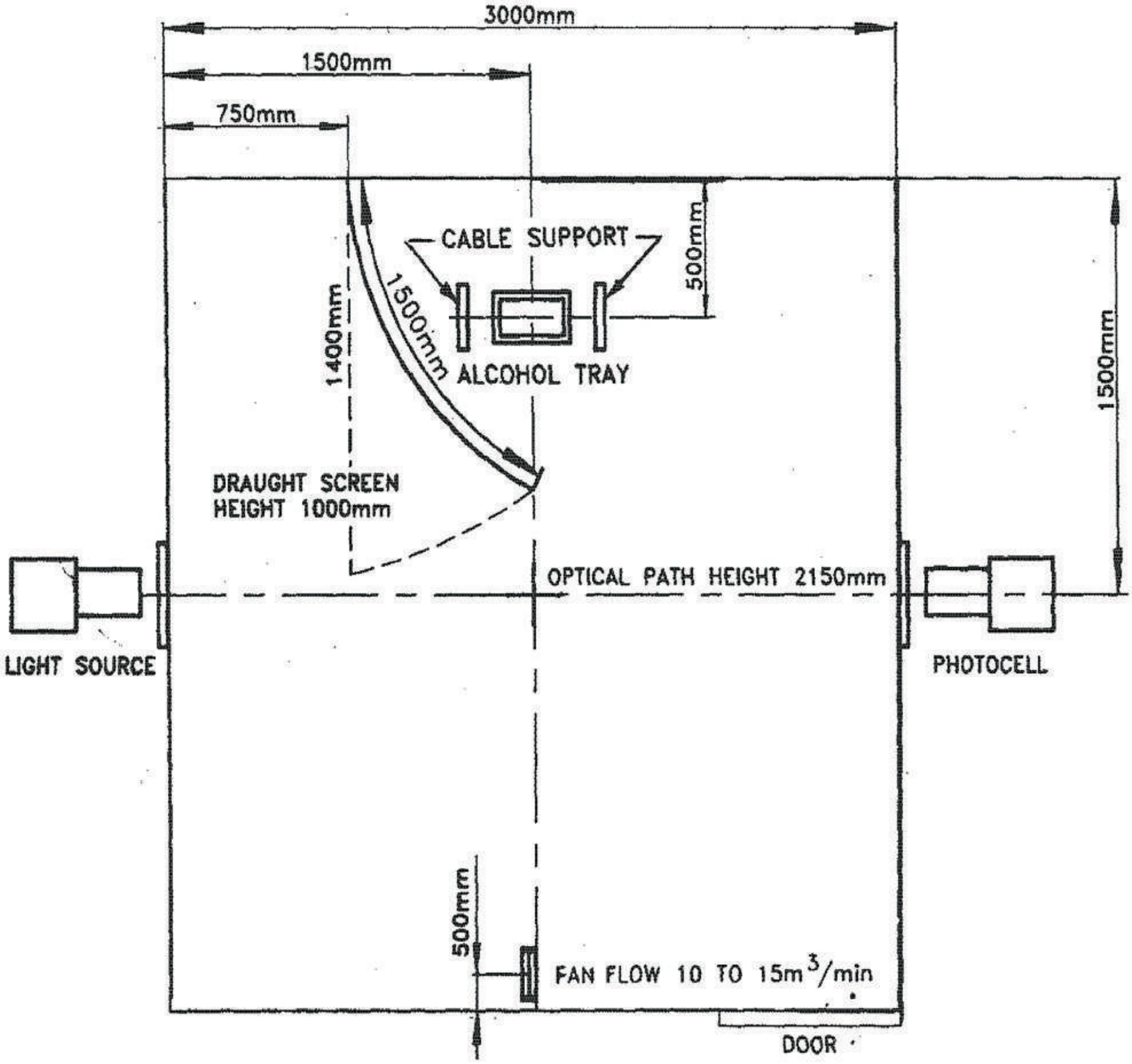


Fig. 2.10 Plan view of test chamber for measurement of smoke density

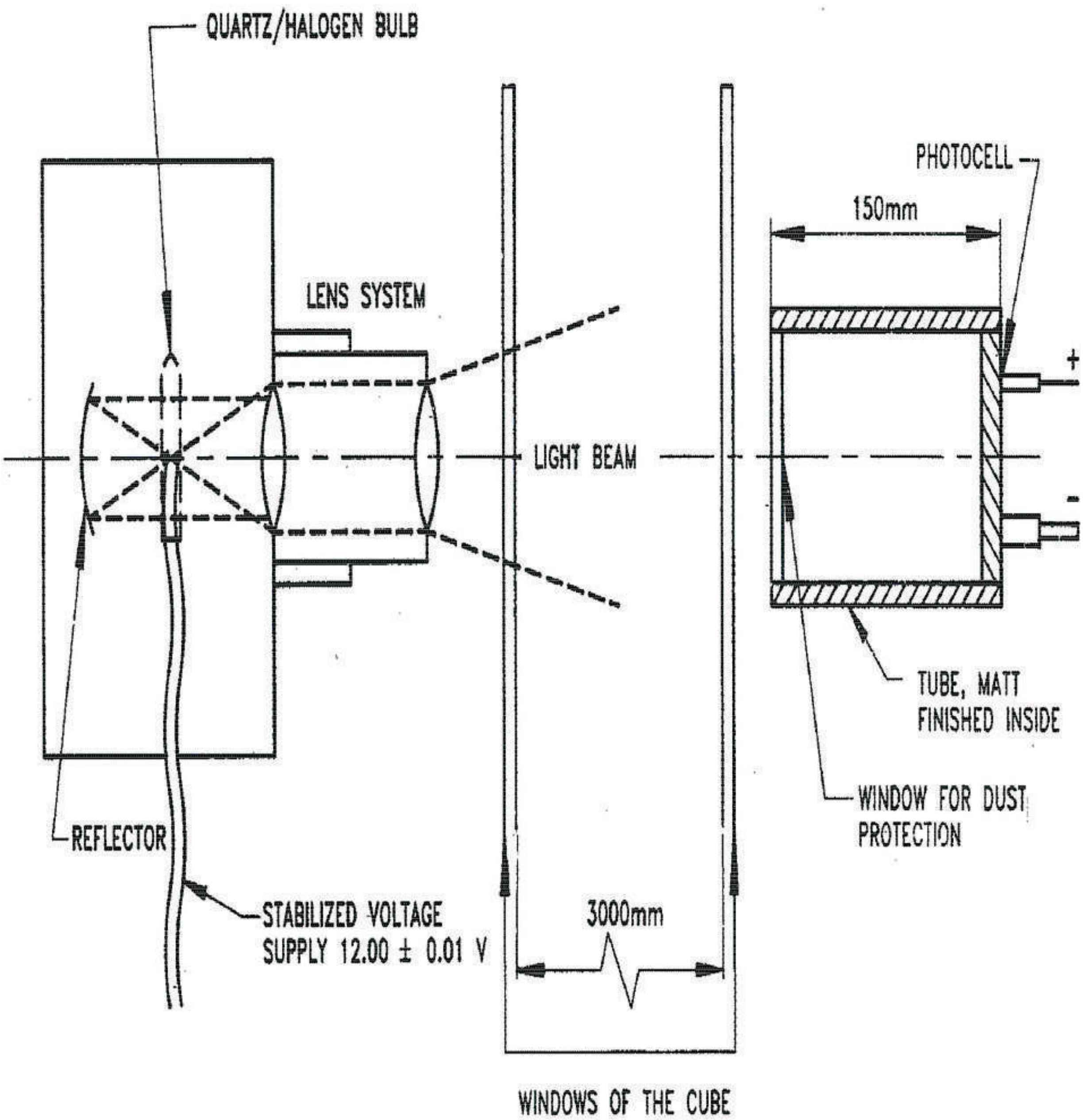


Fig. 2.11 Photometric System

Significance

Evolution of smoke is another hazard from cable that is involved in a fire. The assessment of smoke density is an important factor for evaluating the behaviour of electric cables under fire conditions. Smoke density test describes the method for measurement of smoke emitted when electric cables are burnt under defined conditions. Thus determination of smoke evaluation is another critical performance indicator to assess the smoke emission behaviour of burning cables.

CHAPTER III

OVERHEAD ELECTRICAL CONDUCTORS

CHAPTER III

ALUMINIUM CONDUCTORS FOR OVERHEAD TRANSMISSION PURPOSES

3.1 Different Types of Overhead Conductors

A conductor is one of the most important components of overhead lines. The following are the four common types of aluminium conductors used for overhead transmission purposes to carry generated power from generating stations to the end users:

3.1.1 Aluminium Stranded Conductors

Aluminium Stranded Conductors or All Aluminium Conductors (AAC) are made up of strands of aluminium.

The following Indian Standard deals with aluminium stranded conductors used for overhead transmission purposes:

IS 398 (Part 1) 'Aluminium conductors for overhead transmission purposes - Aluminium Stranded Conductors'

The requirements and tests are explained in various sections as given below:

Section I - General

Section II - Materials

Section III - Dimensions and Construction

Section IV - Packing and Marking

Section V - Tests

Section VI - Tables

3.1.2 Aluminium Conductors, Galvanized Steel Reinforced

Aluminium Conductors, Galvanized Steel Reinforced (ACSR) are made up of aluminium and galvanized steel wires.

The following Indian Standard deals with aluminium conductors, galvanized steel reinforced used for overhead transmission purposes:

IS 398 (Part 2) 'Aluminium conductors for overhead transmission purposes - Aluminium Conductors, Galvanized Steel Reinforced'

The requirements and tests are explained in various sections as given below:

Section I - General

Section II - Materials

Section III - Dimensions and Construction

Section IV - Packing and Marking

Section V - Tests

Section VI - Tables

3.1.3 Aluminium Conductors, Aluminized Steel Reinforced

Aluminium Conductors, Aluminized Steel Reinforced are made up of aluminium and aluminized steel wires.

The following Indian Standard deals with aluminium conductors, aluminized steel reinforced used for overhead transmission purposes:

IS 398 (Part 3) 'Aluminium conductors for overhead transmission purposes - Aluminium Conductors, Aluminized Steel Reinforced'

The requirements and tests are explained in various sections as given below:

Section I - General

Section II - Materials

Section III - Dimensions and Construction

Section IV - Packing and Marking

Section V - Tests

3.1.4 Aluminium Alloy Stranded Conductors (Aluminium-Magnesium-Silicon)

Aluminium Alloy Stranded Conductors (AAAC) are made from aluminium alloy which is a high strength Aluminium-Magnesium-Silicon alloy.

The following Indian Standard deals with aluminium alloy stranded conductors used for overhead transmission purposes:

IS 398 (Part 4) 'Aluminium conductors for overhead transmission purposes - Aluminium Alloy Stranded Conductors (Aluminium - Magnesium - Silicon Type)'

The requirements and tests are explained in various clauses as given below:

- *Material* - *Clause 5*
- *Dimensions and Construction* - *Clause 7, Clause 8, Clause 9 and Clause 10*
- *Packing and Marking* - *Clause 11*
- *Tests* - *Clause 12*

3.1.5 Aluminium Conductors, Galvanized Steel Reinforced for extra high voltage (400 kV and above)

Aluminium Conductors, Galvanized Steel Reinforced (ACSR) are made up of aluminium and galvanized steel wires.

The following Indian Standard deals with aluminium conductors, galvanized steel reinforced for extra high voltage (400 kV and above) used for overhead transmission purposes:

IS 398 (Part 5) 'Aluminium conductors for overhead transmission purposes - Aluminium Conductors, Galvanized Steel Reinforced for extra high voltage (400 KV and above)

The requirements and tests are explained in various clauses as given below:

- *Material* - *Clause 6*
- *Dimensions and Construction* - *Clause 8, Clause 9, Clause 10 and Clause 11*
- *Packing and Marking* - *Clause 12*
- *Tests* - *Clause 13*

3.1.6 High conductivity Aluminium alloy stranded conductors

High conductivity Aluminium Alloy Stranded Conductors (AAAC) are made from special aluminium alloy having lesser resistivity than Aluminium-Magnesium-Silicon alloy.

The following Indian Standard deals with high conductivity aluminium alloy stranded conductors for overhead transmission purposes:

IS 398 (Part 6) 'Aluminium Conductors for Overhead Transmission Purposes - High Conductivity Aluminium Alloy Stranded Conductors'

The requirements and tests are explained in various clauses as given below:

- *Material* - *Clause 5*
- *Dimensions and Construction* - *Clause 9, Clause 10, Clause 11 and Clause 12*
- *Packing and Marking* - *Clause 13*
- *Tests* - *Clause 14*

3.2 Terminology

Stranded Conductor: Conductors twisted together in concentric layers. When the conductor consists of more than one layer, successive layers are twisted in opposite directions.

Direction of Lay: The direction of lay is defined as right hand or left hand. With right hand lay, the wires conform to the direction of the central part of the letter Z when the conductor is held vertically. With left hand lay, the wires conform to the direction of the central part of the letter S when the conductor is held vertically.

Lay Ratio: Ratio of the axial length of a complete turn of the helix formed by an individual wire in a stranded conductor to the external diameter of the helix.

3.3 Materials and Construction

3.3.1 Aluminium Stranded Conductors

The conductors are constructed of hard-drawn aluminium wires (manufactured from EC grade *(Electrical Conductor grade)* aluminium), having mechanical and electrical properties as specified. The aluminium content shall be not less than 99.5 percent and copper conductor shall not be more than 0.04 percent. The wires shall be smooth and free from all imperfections such as spills, splits and scratches.

The nominal diameters of aluminium wires used in the construction are:

2.21, 3.10, 3.18, 3.99, 4.39 and 4.65 mm.

The sizes of stranded conductors are:

25, 50, 100, 150, 240 and 300 mm^2.

The corresponding stranding number and wire diameter are:

7/2.21, 7/3.10, 7/4.39, 19/3.18, 19/3.99 and 19/4.65 mm.

In all constructions, conductors consist of seven or more aluminium wires of the same nominal diameter twisted together in concentric layers. When the conductor consists of more than one layer, the successive layers are twisted in opposite direction and have opposite directions of lay, the outermost layer being right-handed. The wires in each layer shall be evenly and closely stranded. In case of conductors having multiplelayers of wires, the lay ratio of any layer shall not be greater than the lay ratio of the layer immediately beneath it.

3.3.2 Aluminium Conductors, Galvanized Steel Reinforced

The conductors are constructed of hard-drawn aluminium wires (manufactured from EC grade *(Electrical Conductor grade)* aluminium) and galvanized steel wires, having mechanical and electrical properties as specified. The zinc used for galvanizing shall be electrolytic high grade zinc with not less than 99.95 percent purity. The wires shall be smooth and free from all imperfections, such as spills, splits and scratches.

The nominal diameters of aluminium wires used in the construction are:

1.50, 1.96, 2.11, 2.59, 3.00, 3.18, 3.35, 3.50, 3.53, 3.80, 4.09, 4.13 and 4.72 mm.

The nominal diameters of galvanized steel wires used in the construction are:

1.50, 1.57, 1.96, 2.11, 2.30, 2.59, 3.00, 3.18, 3.35, 3.53, 4.09 mm.

The diameter of the galvanized steel wire is taken over the zinc coating.

The sizes of stranded conductors and the corresponding stranding number& wire diameter are as follows:

Conductor Size (mm^2)	Aluminium	Steel
10	6/1.50 mm	1/1.50 mm
18	6/1.96 mm	1/1.96 mm
20	6/2.11 mm	1/2.11 mm
30	6/2.59 mm	1/2.59 mm
50	6/3.35 mm	1/3.35 mm
80	6/4.09 mm	1/4.09 mm
100	6/4.72 mm	7/1.57 mm
150	30/2.59 mm	7/2.59 mm
200	30/3.00 mm	7/3.00 mm
400	42/3.50 mm	7/1.96 mm
420	54/3.18 mm	7/3.18 mm
520	54/3.53 mm	7/3.53 mm
560	42/4.13 mm	72/4.13 mm

For conductors used for extra high voltage overhead power lines (400 kV and above)

The nominal diameters of aluminium wires used in the construction are:

3.53, 4.13 and 4.57 mm.

The nominal diameters of galvanized steel wires used in the construction are:

3.53, 2.30 and 2.54 mm.

The sizes of stranded conductors and the corresponding stranding number & wire diameter are as follows:

Conductor Size (mm^2)	**Aluminium**	**Steel**
520	54/3.53 mm	7/3.53 mm
560	42/4.13 mm	7/2.30mm
690	42/4.57 mm	7/2.54 mm

The ratio of the nominal diameter of the aluminium wires to the nominal diameter of the galvanized steel wires in any particular construction shall be as specified.

In all constructions, conductors consist of seven or more aluminium and galvanized steel wires built-up in concentric layers. The centre wire or wires are of galvanized steel and the outer layer or layers are of aluminium. The successive layers shall have opposite directions of lay, the outermost layer being right-handed. The wires in each layer shall be evenly and closely stranded. In case of conductors having multiple layers of aluminium wires, the lay ratio of any aluminium layer shall not be greater than the lay ratio of the layer immediately beneath it. Steel wires shall be formed during stranding so that they remain intact when conductor is cut for jointing operation.

3.3.3Aluminium Conductors, Aluminized Steel Reinforced

The conductors are constructed of hard-drawn aluminium wires (manufactured from EC grade *(Electrical Conductor grade)* aluminium) and aluminized steel wires, having mechanical and electrical properties as specified. The wires shall be smooth and free from all imperfections, such as spills, splits and scratches.

The nominal diameters of aluminium wires used in the construction are:

1.50, 1.96, 2.11, 2.59, 3.00, 3.18, 3.35, 3.50, 3.53, 3.80, 4.09, 4.13 and 4.72 mm.

The nominal diameters of aluminized steel wires used in the construction are:

1.50, 1.57, 1.96, 2.11, 2.30, 2.59, 3.00, 3.18, 3.35, 3.53 and 4.09 mm.

The sizes of stranded conductors and the corresponding stranding number & wire diameter are as follows:

Conductor Size (mm^2)	Aluminium	Steel
10	6/1.50 mm	1/1.50 mm
18	6/1.96 mm	1/1.96 mm
20	6/2.11 mm	1/2.11 mm
30	6/2.59 mm	1/2.59 mm
50	6/3.35 mm	1/3.35 mm
80	6/4.09 mm	1/4.09 mm
100	6/4.72 mm	7/1.57 mm
150	30/2.59 mm	7/2.59 mm
200	30/3.00 mm	7/3.00 mm
400	42/3.50 mm	7/1.96 mm
420	54/3.18 mm	7/3.18 mm
520	54/3.53 mm	7/3.53 mm
560	42/4.13 mm	72/4.13 mm

The ratio of the nominal diameter of the aluminium wires to the nominal diameter of the aluminized steel wires in any particular construction shall be as specified.

In all constructions, conductors consist of seven or more aluminium and aluminized steel wires built-up in concentric layers. The centre wire or wires are of aluminized steel and outer layer or layers are of aluminium. The successive layers shall have opposite directions of lay, the outermost layer being right-handed. The wires in each layer shall be evenly and closely stranded. In case of conductors having multiple layers of aluminium wires, the lay ratio of any aluminium layer shall not be greater than the lay ratio of the layer immediately beneath it.

3.3.4 Aluminium Alloy Stranded Conductors (Aluminium-Magnesium-Silicon)

The conductors are constructed of heat treated aluminium, magnesium silicon alloy wires having mechanical and electrical properties as specified. For high conductivity aluminium alloy conductors, special aluminium-magnesium-silicon alloy having lesser resistivity is used. The wires shall be smooth and free from all imperfections, such as spills, splits and scratches.

The nominal diameters of aluminium wires used in the construction are:

2.00, 2.50, 2.89, 3.15, 3.31, 3.40, 3.45, 3.55, 3.66, 3.71, 3.81, 3.94, 4.00 and 4.26 mm.

The sizes of stranded conductors are:

15, 22, 34, 55, 80, 100, 125, 148, 173, 200, 232, 288, 346, 400, 465, 525, 570, 604, 642, 695 and 767 mm.

The corresponding stranding number and wire diameter are:

3/2.50, 7/2.00, 7/2.50, 7/3.15, 7/3.81, 7/4.26, 19/2.89, 19/3.15, 19/3.40, 19/3.66, 19/3.94, 37/3.15, 37/3.45, 37/3.71, 37/4.00, 61/3.31, 61/3.45, 61/3.55, 61/3.66, 61/3.81, 61/4.00 mm.

For high conductivity aluminium alloy stranded conductors

The nominal diameters of aluminium wires used in the construction are:

2.00, 2.50, 2.89, 3.08, 3.18, 3.31, 3.40, 3.52, 3.66, 3.81, 4.02 and 4.26 mm.

The sizes of stranded conductors are:

15, 22, 34, 80, 100, 125, 173, 200, 276, 454, 484, 525, 554, 594, 642, 695 and 774 mm.

The corresponding stranding number and wire diameter are:

3/2.50, 7/2.00, 7/2.50, 7/3.81, 7/4.26, 19/2.89, 19/3.40, 19/3.66, 37/3.08, 61/3.08, 61/3.18, 61/3.31, 61/3.40, 61/3.52, 61/3.66, 61/3.81, 61/4.02 mm.

In all constructions, conductors consist of three or more aluminium wires of the same nominal diameter twisted together in concentric layers. The successive layers shall have opposite directions of lay, the outermost layer being right-handed. The wires in each layer shall be evenly and closely stranded. In case of conductors having multiplelayers of aluminium wires, the lay ratio of any aluminium layer shall not be greater than the lay ratio of the layer immediately beneath it.

3.4 Tests

3.4.1 Diameter of individual wires

The diameter of the wire is taken as mean of two measurements at right angles taken at the same cross section. One specimen cut from the sample of individual wire is measured by micrometer having flat surface on both the anvil. The diameter is taken as the average of three diameter measurements each of which is the average of the maximum and minimum reading at a point taken near each end and in the centre of the sample. The diameter of the wire shall be within the limit as specified.

3.4.2 Breaking Load

The breaking load of individual wires, cut from the conductor is determined by means of a suitable tensile testing machine. The load is applied gradually and the rate of separation of jaws of testing machine shall be not less than 25 mm/min and not greater than 100 mm/min. The ultimate breaking load of the wire shall be within the limit as specified.

Significance

The proper choice of material and size of the conductor is of considerable importance for the successful operation of the overhead line. The conductor material used for transmission and distribution of electric power should have high tensile strength in order to withstand mechanical stresses. The strength of the material used in the construction of overhead conductors is assessed through this test.

3.4.3 Ductility Test

This test is applicable for galvanized steel wires or aluminized steel wires only by any of the procedures given below:

a) *Torsion Test*

One specimen cut from the sample of individual wire is gripped at its ends in two vices, one of which shall be free to move longitudinally during the test. A small, tensile load not exceeding two percent of the breaking load of the wire, shall be applied to the sample during testing. The specimen shall be twisted by causing one of the vices to revolve until fracture occurs and the number of twists shall be indicated by a counter or other suitable device. The rate of twisting shall not exceed 60 rev/min.

When tested before stranding, the number of complete twists before fracture occurs shall be not less than 18 on a length equal to 100 times the diameter of the wire. The fracture shall show a smooth surface at right angles to the axis of the wire.

When tested after stranding, the number of complete twists before fracture occurs shall be not less than 16 on a length equal to 100 times the diameter of the wire. The fracture shall show a smooth surface at right angles to the axis of the wire.

b) *Elongation Test*

The elongation of one specimen cut from the sample of individual wire is determined. The specimen is straightened by hand and an original gauge length of 200 mm is marked on the wire. A tensile load is applied and the elongation is measured after the fractured ends have been fitted together. When tested before stranding, the elongation shall not be less than 4 percent. When tested after stranding, the elongation shall not be less than 3.5 percent.

Significance

During construction/ installation procedures, the conductor is subjected to twisting and bending. Ductility test takes into consideration the extent of work hardening which may be caused during stranding process. This test when carried out indicates whether or not the conductor meets the specified requirements for torsion or meets the allowed elongation which is a clear indication of whether the conductor is flexible enough to take any desired bend without breaking.

3.4.4 Wrapping Test

For aluminium wires, one specimen cut from the sample of individual wire is wrapped round the mandrel of diameter equal to wire diameter to form a close helix of eight turns. Six turns shall then be unwrapped and again closely wrapped in the same direction as before. The wire shall not break.

For galvanized steel wires and aluminized steel wires, one specimen cut from the sample of individual wire is wrapped round the mandrel of diameter equal to four times the wire diameter to form a close helix of eight turns. Six turns shall then be unwrapped and again closely wrapped in the same direction as before. The wire shall not break.

> ***Significance***
>
> ***During the manufacturing and installation process, overhead conductors are subjected to torsion caused by axial twisting resulting on possible breakage if the material is not sufficiently ductile. Wrapping test determines the ductility of aluminium wire; the properties of how easily the material can be twisted and wrapped without breaking. Thus performing wrapping test on the sample brings out the property of the material, which makes it suitable for winding and twisting. During the test, if the sample wire does not break it is deemed as ductile thereby ensuring the suitability of material as overhead conductor.***

3.4.5 Resistance Test

The electrical resistance of one specimen cut from the sample of individual wire (before stranding or after stranding) is measured at ambient temperature. The measured resistance is corrected to the value at 20°C by means of the formula:

$$R_{20} = R_T \frac{1}{1+x(T-20)}, \text{ where,}$$

R_{20}= resistance corrected at 20°C,

R_T = resistance measured at T°C,

x = constant mass temperature coefficient of resistance, 0.00403; and

T = ambient temperature during measurement.

> ***Significance***
>
> ***The conductor material used for transmission and distribution of electric power should have high electrical conductivity. The electrical characteristic of the material used in the construction of overhead conductors is assessed through this test.***

3.4 6 Lay Ratio/Direction of Lay

The lay ratio of each layer of the conductor is measured and shall be as per the requirements for each type of construction of the conductor.

> ***Significance***
>
> ***The compliance of overhead conductors to this requirement indicates geometric pattern control/ ideal conductor geometry.***

3.4.7 Surface Condition Test

This test is applicable for ACSR conductors of nominal aluminium area 100 mm^2 and above. A sample of finished conductor having a minimum recommended length of 5m with compression type dead end clamps compressed on both ends in such a manner as to permit the conductor to take its normal straight-line shape, is subjected to a tension of 50 percent of the ultimate breaking load of the conductor. The surface shall not depart from its cylindrical shape nor shall the strands move relative to each other so as to get out of place or disturb the longitudinal smoothness of the conductor. The measured diameter at any place shall be not less than the sum of minimum specified diameter of individual aluminium and steel strands.

> ***Significance***
>
> ***The successful operation of an overhead conductor depends to a great extent upon the mechanical design of the conductor. This test is performed to verify if the surface integrity of the overhead conductor gets disturbed while on usage.***

3.4.8 Ultimate Breaking Load

This test is applicable for ACSR conductors of nominal aluminium area 100 mm^2 and above. A sample of conductor of minimum 5 m length suitably clamped either end is subjected to load, which is increased at a steady rate up to the rated ultimate breaking load and held for one minute. When subjected to the test, the conductor shall not show any fracture. The applied load shall then be increased until the failing load is reached and the value recorded.

> ***Significance***
>
> ***The strength of the overhead conductor is of considerable importance for the successful operation of the overhead line. The stranded conductor used for transmission and distribution of electric power should have high tensile strength in order to withstand mechanical stresses. The strength of the overhead conductor is assessed through this test.***

CHAPTER IV

REGULATORY ROLE OF STANDARDS

CHAPTER IV

REGULATORY ROLE OF STANDARDS

4.1 Introduction

In recent years, there has been an increasing trend in adoption of Standards and Technical Regulations by different countries. While conformity with Standards is voluntary, Technical Regulations are by nature mandatory. The growth in regulatory policy has resulted from the significant improvement in the standard of living of people worldwide, thereby boosting the expectations of consumers towards possessing safe and high-quality products.

The production and availability of quality goods in a country's national market is essential for sustaining economic growth and development. Product quality is important for human health and consumer safety, as well as for protecting the climate and the environment. In the absence of robust product quality culture in a country's economy, the gains made in consumers' confidence will not be commensurate with the rising level national incomes on account of unfulfilment of expected needs and demands of the market.

Standards are always voluntary nature in nature. The standards prescribe specific characteristics of products which include its performance, safety, reliability etc. Maintaining conformity to standards and specifications including their upgradation is ideally driven by market needs.

Whereas, Technical Regulations are by nature mandatory and compulsorily enforced by law. Technical Regulations such as making it mandatory to comply with the safety standards are important because they are one way of ensuring that products are safe for the people. Similar regulations can be important for consumer safety and to protect the environment.

4.2. Technical Regulations / Quality Control Orders

Technical Regulations (TRs), commonly known as Quality Control Orders (QCOs) in India cover different QCOs on various Electrical products, Consumer & Industrial products, Textiles, Chemicals and Petrochemicals as well as Compulsory Registration Orders (CRO) for Electronics & IT products, Solar Photovoltaic products etc.

The power to bring out QCOs and to notify products for compulsory certification vests with the line ministries/ department of the Central Government i.e the regulatory authorities.

4.3 Legislative Instrument for Technical Regulations

The compliance with standards is mandated based on considerations of public interest, protection of human, animal, or plant health, the safety of the environment, prevention of unfair trade practices, national security etc. under the provisions of Section 16 of the Bureau of Indian Standards (BIS) Act, 2016.

Once a product is notified under QCO, no person can manufacture, import, distribute, sell, hire, lease, store, or exhibit for sale any such notified products without BIS Standard Mark except under a valid certification from BIS as per Section 17 of the

BIS Act, 2016. Thus, for such notified products, the manufacturers must compulsorily obtain certification from BIS for use of Standard Mark and ensure product conformity to the requirements specified in the relevant Standards.

The Domestic Laws / Rules / Orders / Regulations applicable to domestically produced goods shall apply, mutatis mutandis, to imports unless specifically exempted. If the domestic product(s) are subjected to mandatory compliance with Indian Standards, such product(s) if imported would also need to comply with Indian Standards compulsorily. Thus, for these products, the manufacturer in a foreign country will also be required to obtain certification from BIS, use Standard Mark, and ensure conformity of their products exported to India.

4.4 Technical Regulations – Impact on India's Quality Ecosystem

The role of QCOs becomes pivotal in achieving the aim of 'Atma Nirbhar Bharat" considering its twin objectives of developing of a robust quality ecosystem in the country and providing the consumers with quality goods meeting the global benchmark. India's competitiveness in manufacturing and the success of 'Make in India' depends on its ability to produce high-quality products.

4.5 Role of BIS in enforcing Quality Rules in India

BIS, the National Standards Body of India, is engaged in the harmonious development of the activities of standardization, conformity assessment, and quality assurance of goods and articles. The conformity assessment activities of BIS aim at the assurance of the quality of goods.The Indian Standards established by BIS forms the basis for the Product Certification Schemes, which provides Third Party Assurance of Quality of products to consumers.

The product certification under different schemes is operated by BIS as per the provisions of the BIS (Conformity Assessment) Regulations, 2018, providing its services to various stakeholders (like Consumers, Industry including MSMEs, Government etc.) as well as foreign manufacturers who intend to export their products to India. The product certification scheme isprimarily voluntary.

Conformity assessment as a tool to ensure compliance is gaining importance considering the third-party assurance on the quality of the product. Thus, various line ministries/ departments of the Central Government are also utilising the services of BIS towards the fulfilment of objectives w.r.t. regulatory compliance based on various conformity assessment schemes.

4.6 Significance of BIS conformity assessment activities in ensuring Quality through Technical Regulations

The product certification activities of BIS based on technical regulations act as a key pillar of quality infrastructure in the country. The functioning of the quality eco-system is supported by a certification function through which benefits are derived across various segments as given below:

(a) ***Consumers*** - The certification mark on a product conveys to the consumers that the product fulfils the requirements for characteristics such as safety, quality, performance, reliability, or impact on the environment.

(b) ***Industry including MSMEs*** - The opportunity for the enterprise is facilitated through this level playing field of certification activity operated through various conformity assessment schemes of BIS. Indian manufacturers, especially micro & small enterprises, derive tangible benefits through conformity assessment schemes of BIS in terms of competing with other large-scale manufacturers and gaining access & acceptability in the domestic market.

(c) ***Government*** - The regulatory authorities use the tool of product certification, especially where non-conformities may have serious consequences. The common consumers do not always have the resources and capacity to check product compliance. The compulsory mandate of product certification and the presence of certification mark aim at fulfilling the regulatory objectives. Further, for various other stakeholders like Ministries (Central as well as State) and organisations there under including the public sector undertakings and autonomous organisations/institutions, the purchase of products with BIS Standard Mark reduces the burden of repeat testing of the product to verify the quality.

(d) ***International trade*** - Product certification aids in gaining the confidence of consumers across the globe. Many domestic manufacturers gain first-hand experience with certification through BIS only and get geared and fine-tuned to the certification requirements of potential export destinations.

EXERCISE

EXERCISE

a) Briefly explain the different type of materials and form of electric conductors which is used in the manufacturing of electric cables?

b) Explain what is meant by flexibility class of cables?

c) What is the significance of persulphate test for copper conductors?

d) What is the significance of annealing test on conductors?

e) Briefly explain the procedure of annealing test on copper conductors?

f) Explain the procedure of wrapping test on Aluminium conductors?

g) Explain about any two types of insulation and sheath for cables?

h) What is the significance of loss of mass test?

i) Explain the heat shock test on cables?

j) Name any two types of cables and explain its features?

k) Explain the flammability test on cables?

l) Whys is assessment of halogen acid gas evolution important?

m) What are the different types of Overhead conductors?

n) Define direction of lay and lay ratio?

o) What is torsion test on steel wires?

REFERENCES

Chapter	Reference Document	Title
		Indian Standards on Materials
II	IS 5831	PVC Insulation and Sheath of Electric Cables
	IS 6380	Elastomeric Insulation and Sheath of Electric Cables
	IS 8130	Conductors for Insulated Electric Cables and Flexible Cords
		Indian Standards on Cables
II	IS 694	Polyvinyl Chloride (PVC) Insulated Unsheathed and Sheathed Cables/Cords with Rigid and Flexible Conductor for Rated Voltages up to and including 450/ 750 V
	IS 1554 (Part 1)	PVC Insulated (Heavy Duty) Electric Cables for working voltages up to and including 1100 V
	IS 1554 (Part 2)	PVC Insulated (Heavy Duty) Electric Cables for working voltages from 3.3 kV up to and including 11 kV
	IS 7098 (Part 1)	Cross-linked Polyethylene Insulated PVC Sheathed Cables for working voltages up to and including 1100 V
	IS 7098 (Part 2)	Cross-linked Polyethylene Insulated PVC Sheathed Cables for working voltages from 3.3 kV up to and including 33 kV
	IS 7098 (Part 3)	Cross-linked Polyethylene Insulated PVC Sheathed Cables for working voltages from 66 kV up to and including 220 kV
	IS 9968 (Part 1)	Elastomer Insulated Cables for working voltages up to and including 1100 V
	IS 9968 (Part 2)	Elastomer Insulated Cables for working voltages from 3.3 kV up to and including 33 kV
	IS 14255	Aerial Bunched Cables for working voltages up to and including 1100 Volts
	IS 16246	Elastomer Insulated Cables with limited circuit integrity when affected by fire
	IS 17293	Electric Cables for Photovoltaic Systems for rated voltage 1500 V d.c.
	IS 17048	Halogen Free Flame Retardant (HFFR) Cables for working Voltages up to and including 1100 Volts
	IS 17505 (Part 1)	Thermosetting Insulated Fire Survival Cables for fixed installation having low emission of smoke and corrosive gases when affected by fire for working Voltages up to and including 1100 V AC and 1500 V DC - Requirements for Armoured Cables

Indian Standards on Testing of Cables		
II	IS 10810 (Part 1)	Methods of Test for Cables - Annealing Test for Wires used as Conductors
	IS 10810 (Part 2)	Methods of Test for Cables – Tensile Test for Aluminium Wires
	IS 10810 (Part 3)	Methods of Test for Cables – Wrapping test for Aluminium Wires
	IS 10810 (Part 4)	Methods of Test for Cables - Persulphate Test of Conductor
	IS 10810 (Part 5)	Methods of Test for Cables – Conductor Resistance Test
	IS 10810 (Part 6)	Methods of Tests for Cables – Thickness of Thermoplastic and Elastomeric Insulation and Sheath
	IS 10810 (Part 7)	Methods of Test for Cables - Tensile Strength and Elongation at Break of Thermoplastic and Elastomeric Insulation and Sheath
	IS 10810 (Part 10)	Methods of Test for Cables – Loss of Mass Test
	IS 10810 (Part 12)	Methods of Test for Cables - Shrinkage Test
	IS 10810 (Part 14)	Heat Shock Test
	IS 10810 (Part 15)	Methods of Tests for Cables – Hot Deformation Test
	IS 10810 (Part 43)	Method of Tests for Cables – Insulation Resistance
	IS 10810 (Part 45)	Methods of Tests for Cables – High Voltage Test
	IS 10810 (Part 53)	Methods of Test for Cables – Flammability Test
	IS 10810 (Part 58)	Method of Tests for Cables - Oxygen Index Test
	IS 10810 (Part 59)	Methods of Test for Cables - Determination of the amount of Halogen Acid Gas evolved during combustion of polymeric materials taken from Cables
	IS 10810 (Part 63)	Method of Tests for Cables - Measurement of Smoke Density of Electric Cables under Fire Conditions
	IS 10810 (Part 64)	Methods of Test for Cables - Measurement of Temperature Index
Indian Standards on Conductors		
III	IS 398 (Part 1)	Aluminium Conductors for Overhead Transmission Purposes - Aluminium Stranded Conductors
	IS 398 (Part 2)	Aluminium Conductors for Overhead Transmission Purposes - Aluminium Conductors, Galvanized Steel Reinforced

	IS 398 (Part 3)	Aluminium Conductors for Overhead Transmission Purposes - Aluminium Conductors, Aluminium Steel Reinforced
	IS 398 (Part 4)	Aluminium Conductors for Overhead Transmission Purposes - Aluminium Alloy Stranded Conductors (Aluminium - Magnesium - Silicon Type)
	IS 398 (Part 5)	Aluminium Conductor for Overhead Transmission Purposes - Aluminium Conductors Galvanized Steel Reinforced for Extra High Voltage (400 KV and above)
	IS 398 (Part 6)	Aluminium Conductors for Overhead Transmission Purposes - High Conductivity Aluminium Alloy Stranded Conductors