Fire Performance of Electric Cables
- new test methods and measurement techniques
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Synthesis Report

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Partners:

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CESI	Centro Elettrotecnico Sperimentale Italiano	Italy
SP	Sveriges Provnings- och Forskningsinstitut	Sweden
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Project Co-ordinator: SP
Project Management: IC

Summary

Current European national fire assessment techniques are not sensitive enough to differentiate between cables with reasonable fire properties and those with very good properties needed for high hazard installations or for high-density telecommunications installations.

The FIPEC research programme was set up to develop methods for measuring the fire performance of electric cables (FIPEC) based on sound engineering principles rather than prescriptive tests as the former will help facilitate the use of good measurement techniques and the introduction of fire engineering in this field.

The FIPEC work programme comprised of the development of the fire test procedures and investigation of mathematical fire models to predict fire development in real-scale scenarios from smaller scale experiments. These procedures have been developed and draft standard guidance documents written and made available to national standardisation groups and CEN/CENELEC. The techniques used, which include heat release measurement, have been developed for use with existing IEC test methods to provide a more comprehensive assessment system. The modifications to the IEC test method increases the test sensitivity and hence service a wider range of fire performance levels than current methods.

The FIPEC programme included a review of European cable installations, experiments on electric cables and the materials from which they are constructed and modelling studies. The experimental work has being carried out using specimens that represent a wide spectrum of fire behaviour and this was undertaken at different scales and linked by correlation and fire modelling studies, which are the scientific foundations for assessment techniques. The experiments have been carried out at four scales ranging from small material samples to real-scale cable installations.

Test data from almost 2000 experiments are held in a database. The data base management protocols have been established and software generated to convert all data into a common format.

The real-scale scenario tests are the reference scenarios and the full-scaletests based on IEC 60332-3, have proved to correlate well with both horizontal and vertical real-scale scenario cable tests. Thus the IEC 60332-3 modifications made within this project allow the use of the method as a good representation of both horizontal and vertical scenarios.

Round robin studies have shown that these modified IEC 60332-3 test procedures are highly repeatable and reproducible.

The results of the full-scale modified IEC 60332-3 tests can readily be used as a basis for classification of the fire development and smoke development rates of the cables. The test methods give continuous measurements rather than pass/fail results and hence regulators can select any number of classes with appropriate performance levels. An example of a classification system is given but this can be readily modified to be especially sensitive to specific performance groups.

Cone calorimeter testing protocols have been developed both to measure the heat release and smoke release properties of cables and the materials from which they are made. Round robin studies have shown that these small-scale test procedures are highly repeatable and reproducible.

Both small and full-scale testing show a good sensitivity to differing levels of cable fire performance and offer the basis of an assessment or classification system. The test procedures and experiences gained in this programme are being passed to the EC, sponsors, CENELEC, CEN, and to the Cable Making Industry to assist development of better assessment methods.

Simultaneously different types of modelling have been performed between small, full and real-scale tests. This resulted in a number of correlation formulae, numerical flame spread models and advanced CFD (computational fluid dynamics) modelling. The latter will allow cable fires in more complex situations to be predicted in the future and it is proposed that further efforts are made in this area. Also a first approach to a composite model based on a physical pyrolysis model has been performed. This composite model allows the prediction of the fire behaviour of the cable in the cone calorimeter by means of test results of the different materials used in the cable construction. The approach is very novel and can still be improved but is very promising. The FIPEC project has considered models that

were beyond the original proposal and has opened new areas for advanced research of fire development of cable fires.

1 Background

Existing European national fire assessment techniques are not sensitive enough to differentiate between cables with reasonable properties and those with very good properties required for high hazard installations or for high-density telecommunications installations. Several major users in these fields have independently issued their own test methods so there is a clear need for a more sensitive harmonised standard in order to avoid proliferation of purchasers specifications.

Newer assessment techniques and standards should be based on sound engineering principles rather than being prescriptive as this will help facilitate the use of good measurement techniques and the introduction of fire engineering. The major hazard for cable installations is fast fire development, which in turn is linked to heat release rate, of any ignited materials. Heat release is measured by fire calorimetry and it is appropriate that modern calorimetry techniques be used in this industry.

A calorimetry test, adapted to the standard IEC 60332-3, which enables the industry to use existing methods for general usage, but gives the sensitivity to allow for further classification for high risk installations, would be acceptable to most European groups as it enables all existing assessment to remain valid.

It was proposed that this project would generate the scientific basis for these developments and would also provide drafts for the standards and classification systems. The latter was to be based on full-scale tests and where feasible small-scale tests, to predict classifications.

Large commercial savings could be made by cable manufacturers who would only then need to perform one test in order to classify cables for several applications. In cases where small-scale calorimetry suffices the saving would be even greater as this removes the need for extensive prototype cable production for test purposes. This would be of even greater commercial advantage to cable material suppliers, who often do not have the facilities to produce electric cables needed for fire assessments.

2 Objectives

The scientific and technical objectives of this programme were to:

1. Develop or modify fire test methods for electrical cables offering improvements on existing IEC test methods so that
   - existing classification systems can be maintained
   - new classifications are based on scientifically sound measurement techniques rather than prescriptive methods
   - the sensitivity of measurement is enhanced, to allow for subdivisions in any classification, especially at the better fire performance levels
   - new types of cables, e.g. optical fibre cables, can be tested
   - safety of operation of procedures is improved over that in existing test methods
2. Develop or adapt the cone calorimeter test in order to be able to use it for small-scale testing of electrical cables.
3. Develop correlation models for the prediction of fire performance of electrical cables based on the results of the small-scale tests.

4. Develop bases for calculation models for the prediction of realistic fire performance of electrical cables, in some key constructions, based on the results of small-scale tests on materials.
5. Investigate the validity of models developed by comparing the output from models with realistic design fire tests data.

3 Project Programme

The project has been a large programme involving many different types of tasks such as cable selection, data management of fire tests and model development. 4 partners from 4 member states carried out the work over a three-year period with materials and cables supplied from industry from most member states.

Management comprised of a project management from Interscience Communications Ltd (IC) in the UK and financial management from Sveriges Provnings-och Forskningsinstitut (SP) in Sweden. Technical management was shared between IC and SP and the overall responsibility for this report has rested with the project manager and the SP technical co-ordinator. This programme consists of 18 work packages, each of which was undertaken by several laboratories. These are detailed in Table 1.

IC was responsible for the technical leadership of WPs dealing with the small-scale testing programme (3, 4, 8, 9), and performed a significant proportion of the testing work in these WPs and participated in WP1 and WP5. IC also led the correlation WPs and much of the technical analysis associated with them (10, 11, 12) and the data management and programme management (WP 16, 17). IC was also responsible for the development of the small-scale test procedure (WP 15) and was responsible for WP 14 (measuring system and performance groups).

CESI performed most of the work and technical leadership on projects associated with review of cable installations (WP 1) and the selection and production of cables (WP 5). CESI also participated in the technical work of WPs associated with small-scale testing (3, 4, 8, 9) and full-scale testing (7) and the correlation studies (12).

ISSeP, participated in the technical work of WPs associated with small-scale testing (8, 9) and full-scale testing (2,7) and the correlation studies (11).

SP was involved in data management, project management and reporting (WPs 16, 17, 18). They had technical leadership for the real-scale and full-scale fire test WPs (2, 6, 7) and carried out a significant fraction of the technical work in these work items. SP contributed technically to the small-scale testing (8, 9) and correlation (10, 11) work items. SP performed most of the mathematical modelling (WP 13) and was responsible for the composite material model (enhancement of WP 12).

SP also produced the full-scale guidance document (WP 15) and was involved in WP 14 dealing with the different performance groups.

WP	Title
WP 1	Review of European cable installations and planning of real-scale scenarios test series
WP 2	Investigate the effects of variables on a full-scale test
WP 3	Develop small-scale cable test that can determine the essential parameters
WP 4	Develop small-scale material test
WP 5	Construct cables
WP 6	Conduct real-scale fire tests
WP 7	Conduct full-scale standard tests
WP 8	Conduct small-scale cable tests
WP 9	Conduct small-scale tests on materials (sheaths and insulations)
WP 10	Validate full-scale standard tests by correlation to real-scale tests in the European scenarios defined in WP 1
WP 11	Correlate the small-scale test results to the full-scale standard test results
WP 12	Develop bases for correlation of results of small-scale tests on materials to small-scale test results on cable used in WP 11
WP 13	Development of a mathematical model for the prediction of heat release rate and flame propagation of burning cables in real fires and full-scale tests from the results of small-scale tests on cable specimens
WP 14	Develop a measurement system proposal based on the existing measurement system and the information obtained
WP 15	Prepare guidelines for use in the production of standards
WP 16	Data management
WP 17	Programme management
WP 18	Final report

Table 1 List of FIPEC work packages

4 Project Programme

The programme consisted of the development of a new measurement technique for assessing the fire performance of electric cables. This has been developed and guidance documents, which are being made available to national standardisation groups and CEN/CENELEC, have been drafted. The techniques used, which include heat release measurement, have been developed for use with existing test methods to provide a more comprehensive assessment system, which is both more precise and sensitive and hence services a wider range of fire performance levels than current methods. The programme has included a review of and experiments on electric cables and the materials from which they are constructed. The experimental work was conducted at different scales and linked by correlation and fire modelling studies that form the scientific foundations for assessment techniques. Assessments can also be based on small-scale tests to give maximum commercial and operational benefits to the electric cable making industry, its suppliers and customers. Various types of models were evaluated between the different levels of testing.

The experiments have been carried out at four scales ranging from small material samples to real-scale cable installations. The real-scale scenario tests are the reference scenarios. The four testing scales are:

1. Real-scale scenario tests carried out on reproductions of electric cable installations
2. Full-scale standard tests carried out on cable trays (based on IEC 60332-3 and smaller scale than 1)
3. Small-scale tests on cables carried out in a cone calorimeter
4. Small-scale tests on materials carried out in a cone calorimeter

5 Cable and Scenario Selection

The selection of cables and materials for use in this programme was made after a review of European Cable installations. This was carried out by consultation with the industry and using the results of a questionnaire, which was answered by major cable suppliers and users.

A review of the types of premises in which cables are installed has been made in order to define which are likely to constitute a significant fire risk and what type of installation techniques and cables are likely to be used in such premises. These have been classified based on the level of potential fire risk and on the local environments of the installations. They are further sub-classified by the nature of the zone immediate to the cable installation.

The amount and type of cables mounted together in each of these applications (and the presence of other fuels) has been investigated. This was analysed in terms of the construction, dimensions and types of materials and mounting techniques used and the environmental conditions. Information on the types of cables and installations used in each application have been analysed and used to select the test scenarios in real-scale tests and the cables and materials selected and procured for use in all testing WPs.

4 types of key fire-sensitive cable installations were identified. These were:

1. Power plants,
2. Vehicles (trains, ships and aircraft),
3. Tunnels
4. Occupancies (e.g. control rooms, under -floor voids, ceiling voids and riser shafts)

6 Management of Data

The amount of fire tests that have been performed in FIPEC is large with almost 70 real-scale tests, 225 full-scale tests and more than 1500 cone calorimeter tests. This necessitated a reliable system for processing, storing and sharing test data which is often collected using different software and different data base systems. Each test performed generated a large amount of time history parameters.

Data conversion software was produced and a data bank was set up. A data management system called the Fire Data Management System (FDMS) was improved and developed to accommodate the needs of FIPEC. This data management work ran continuously during the whole of the project.

7 The FIPEC Test Protocols

Fire testing electric cables requires rational and reliable test methods. Real-scale, full-scale and small-scale test methodologies were developed within FIPEC to provide the data needed for efficient and accurate evaluation of the fire performance of electric cables in common installations.

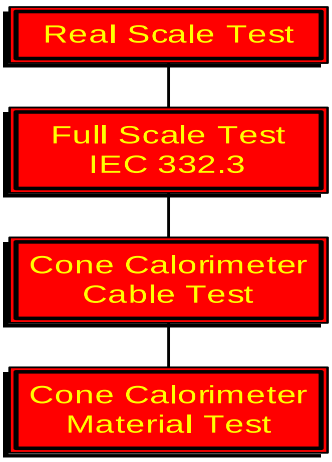

Figure 1 Levels of testing in FIPEC

The real-scale tests were developed as a result of information gathered in WP 1 and were the primary reference for all other scales of testing. The full-scale tests used were derivatives of the IEC 60332-3 test method. The IEC test apparatus was instrumented to measure heat release and smoke release rates, which are essential parameters in assessing the fire development rates of electric cables. These are also essential parameters for use in the modelling work as they can be measured accurately at real, full and small scales. The FIPEC full-scale tests method has been included in the final report

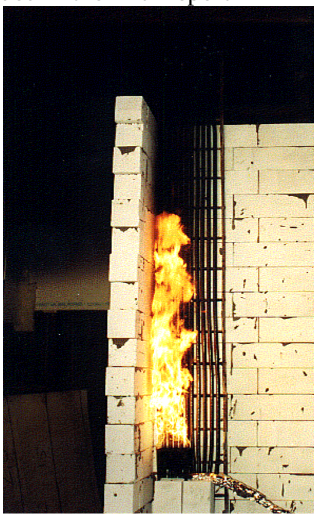

Figure 2 Example of horizontal and vertical real-scale test

The small-scale tests used were based on the Cone calorimeter (ISO 5660), which is a very versatile fire test method that can be used for many materials and applications. The test methods have been investigated and specific test protocols developed to specify how cables and cable materials should be tested. This work has demonstrated that sample preparation is important in ensuring accurate and repeatable test results. The FIPEC small-scale tests methods are described in the final report. All test protocols have been validated by round robin activity.

Figure 3 The Cone Calorimeter, a small-scale test method for cables used for modelling cables and for product development

8 Standards and Guidance Documents

The protocols developed for both the full-scale and small-scale tests have been used to develop documents based on IEC 60332-3 and ISO 5660 for use in the standardisation process either by CEN, CENELEC or IEC. These are reproduced in the final report.

9 FIPEC Modelling

In order to create links between the larger and smaller scale testing and to simplify the fire assessment of electric cables, FIPEC research has evolved fire models. Both physics-based fire models and correlation formulae have been developed and available computer codes have been evaluated. Validation of the full-scale tests has been performed using ranking order and parameter correlations with the real-scale test data. Results from this work are presented in the report.

Linear correlations have been studied between the different scales of cable testing. Between cable material tests and cable tests in the Cone Calorimeter a qualitative analysis has been conducted.
Prediction of performance of cables in the real-scale test scenario can be performed by a linear correlation based on the full-scale test data. A similar linear correlation model has been developed between the cone calorimeter and the full-scale test. Additionally thermal flame spread models were fine-tuned in order to be used in predicting flame spread and heat release of cables in the full-scale tests. These models can, if used appropriately, also be used in a wider application.

In addition to the thermal flame spread, experience was built up with the use of physical flame spread models and their corresponding pyrolysis models. An existing approach of a pyrolysis model was modified in such a way that it could be used for cables.

With this model a stand-alone physical flame spread model was developed. A case study was made with a CFD model (computational fluid dynamics). This approach opens a new area of applications with less restriction.

The same physical model was used when developing a procedure for prediction of cable fire behaviour by means of material test data. A novel procedure was established allowing the calculation of the cable behaviour in the cone calorimeter by means of material data. For such models some semi-material parameters are required and these have been determined from Cone Calorimeter test results.

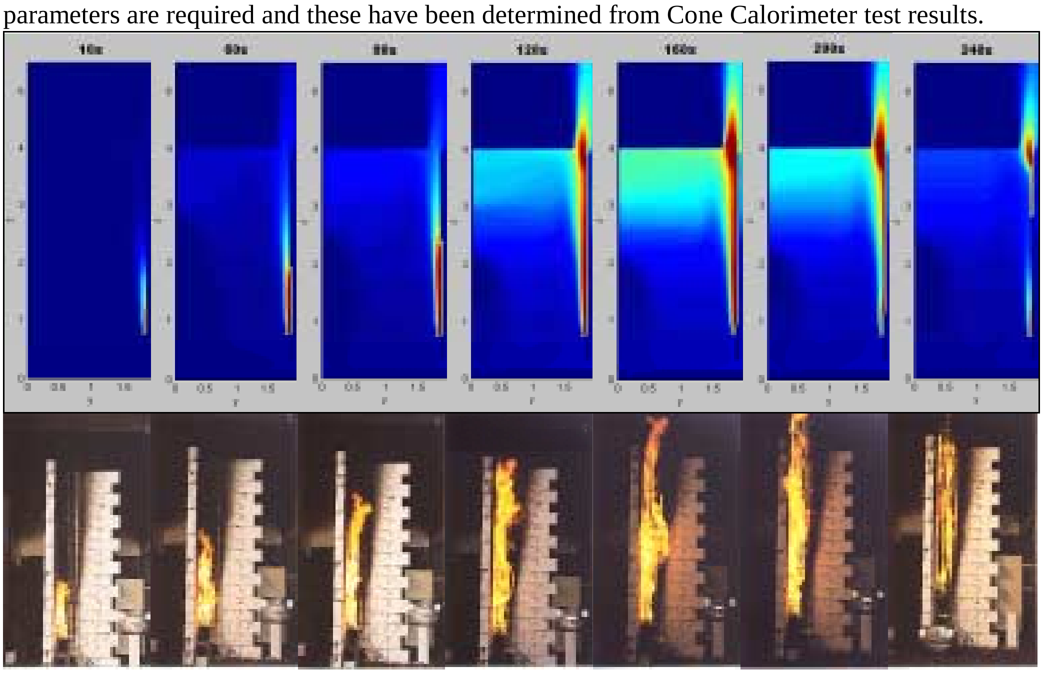

Figure 4 Example of flame spread modelling inside a CFD code (simulation and experiment)

10 Cable Classification

The results of the full-scale modified IEC 60332-3 tests can readily be used as a basis for classification of the fire development and smoke development rates of the cables. The test methods give continuous measurements rather than pass/fail results and hence regulators can select any number of classes with appropriate performance levels. An example of a classification system is described which consists of 5 basic classes for fire development and three smoke classification groups. This can be readily modified to be especially sensitive to specific performance groups.

11 Exploitation

The major route for exploitation of the project results is the development of information that can be readily used by standardisation bodies for the development of IEC, CENELEC or national standards. IEC committee TC20 is aware of the aims of the FIPEC project through interaction between the partners and the chairmen and secretary of this group.

The EC DG III is developing methods of tests for construction products. Recent discussions concluded that cables needed to be include in the CPD and that the test methods proposed for assessing wall and ceiling linings were not appropriate for cables testing. There is therefor a need for a European standard for electric cable assessment. The Standards guidance generated in FIPEC has been prepared and passed to representatives from CEN/CENELEC and Europacable, to aid this. First drafts of full-scale testing method have been prepared and sections passed to representatives of CEN and CENELEC who have used this information as the basis of representations to DG III for use in assessing cables under the construction products directive. The full-scale test in particular works exceptionally well in providing the basis for classifications. The latter can be formatted to be sensitive at any section of the performance range.

The final report has been sent to DG III to assist in their work and FIPEC representatives have been invited to attend a group of European regulators to present the finding of the project and to discuss how these may be of use in reaching their objectives. FIPEC partners will make themselves available to co-operate with EC regulators and standardisation groups developing fire test methods for cables.
Individual partners will inform national standardisation groups in the partner countries of the project aims.

Dissemination of information will also be made via conferences and by means of specifically convened meetings and workshops.

12 Conclusions

Full-scale testing protocols based on modified IEC 60332-3 have been developed and validated.
Repeatability and reproducibility work has shown that these full-scale test procedures are highly repeatable and reproducible.

The results of the tests carried out on the database cables correlate well using data from the real-scale tests undertaken both in horizontal and vertical scenarios. The IEC 60332-3 modifications made within this project allow the use of the method as a good representation of both horizontal and vertical scenarios. The project demonstrated that the parameter that has the most effect on the test results is the method of mounting of the tested cables.

The developed method can be used both for prescriptive testing and for application in fire performance-based codes where mounting procedures different to the prescriptive ones can be used.
The results of the full-scale tests can readily be used as a basis for classification of the fire development and smoke development rates of the cables under fire conditions. Cone calorimeter testing protocols have been developed both to measure the heat release and smoke release properties of cables and the materials from which they are made. Repeatability and reproducibility work has show that these small-scale test procedures are highly repeatable and reproducible.

The modelling and prediction studies resulted in different links between cone calorimeter testing and full-scale testing. These links range from simple correlation models to advanced physical flame spread models.

While traditional thermal flame spread analysis was used for the numerical modelling, two breakthroughs were obtained in the prediction of cable performance. One was a case study of a stand-alone physical flame spread model inside a CFD code. The other one was the application and adaptation of a pyrolysis model for the prediction of the HRR of a cable by means of material test data of which the cable is composed. Whilst both type of approach can still be improved considerably, the FIPEC project has shown that a new area of numerical modelling has started.

Both small and full-scale testing show a good sensitivity to differing levels of cable fire performance and offer the basis of an assessment or classification system. The test procedures and experiences gained in this programme are being passed to the sponsors, to CENELEC, CEN and IEC, and to the European Cable Making Industry to assist development of better assessment methods. The latter are using this information to help develop standard test methods and classification systems for electric cables to be used by DG III in support of the Construction Products Directive.

13 Conference Presentations and Publications

1. 3rd-4th February 1998 Flame Retardants 98 conference, London UK, *The FIPEC project Fire Testing Electric Cables*; van Hees, Vercellotti, Breulet and Grayson
2. 1st July 1998, Fire Hazards of Cables in Buildings, Fire Research Station BRE, Watford, UK. *The FIPEC project Fire Testing Electric Cables*; van Hees, Vercellotti, Breulet and Grayson
3. 14th-16th September 1998 Plastics in Telecommunications VIII, London, UK, *The FIPEC project (Fire Performance of Electrical Cables)*; van Hees, Vercellotti, Breulet and Grayson
4. 23rd-24th February 1999, Fire and Materials Conference, San Antonio, Texas, USA, *The FIPEC project (Fire Performance of Electrical Cables),* P. van Hees, U. Vercellotti, H. Breulet and S. Grayson
5. 20th-24th June 1999 -JiCable Conference, Paris, France, *Updated Status of the FIPEC project (Fire Performance of Electrical Cables),* P. van Hees, U Vercellotti, H Breulet S. Grayson and A. Green
6. 29th June-1st July 1999, Interflam '99, Edinburgh, Scotland, *An overview of the real-scale tests in the FIPEC project*, P. van Hees, U Vercellotti, H Breulet, S. Grayson and A. Green
7. 12th -13th February 2000 Flame Retardants 2000 conference, London, UK, *Assessing the fire performance of electric cables* (*FIPEC),* P. van Hees, J. Axelsson, U Vercellotti, H Breulet, S. Grayson and A. Green
8. 26 April, International Fire Conference for Wire and Cable London, Assessing the fire performance of electric cables (FIPEC) P. van Hees, J.Axelsson, U Vercellotti, H Breulet, A. Green and S. Grayson
9. 22nd -24th May 2000 Recent Advances in Flame Retardancy of Polymeric Materials, Stamford USA, *Assessing the fire performance of electric cables* (*FIPEC),* P. Van Hees, A. M. Green, S. J. Grayson, U Vercellotti, H Breulet
10. Fire and Materials Journal, Volume 25 nr 2, pp *49-60, Assessing the fire performance of electric cables* (*FIPEC),* P. Van Hees, A. M. Green, S. J. Grayson, U Vercellotti, H Breulet, Wiley Publications
11. Fire and Materials Journal, Volume 25 nr 4, pp169-178, *Mathematical modelling of fire development in cable installation,* P. Van Hees and J. Axelsson, A. M. Green and S. J. Grayson,. Wiley Publications
12. FIPEC Final Report on the Europeans Commission SMT Programme SMT4-CT96-2059, 410pp, ISBN 0 9532312 5 9, Interscience Communications Ltd London 2000.
13. 12-14 March 2001, FRCA Spring conference 2001, San Francisco,. P. Van Hees and J. Axelsson, A. M. Green and S. J. Grayson, *”Assessing the fire performance of electric cables (FIPEC)”*

14 19-21 March 2002, Cables 2002, Cologne Germany, P. Van Hees and J. Axelsson, A. M. Green and S. J. Grayson, *Fire Performance of Electrical Cables.*