ASSESSING THE FIRE PERFORMANCE OF ELECTRIC CABLES (FIPEC)

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ABSTRACT

The FIPEC project is a research project funded by DG XII of the European Commission and co-financed by several European cable manufacturers, materials suppliers, cable users and governmental research bodies. The FIPEC project has developed different levels of testing ranging from a small-scale, cone calorimeter test procedures developed for cables and materials, a full-scale-test procedure based on the IEC 60332-3, but utilising HRR and SPR measurements, and a real scale test.

The FIPEC project [1][2][3][4] had the following objectives:

- Develop or modify fire test methods for electrical cables offering improvements on existing IEC test methods.
- Develop or adapt the cone calorimeter test in order to be able to use it for small scale testing of electrical cables.
- Develop a correlation model for the prediction of fire performance of electrical cables based on the results of small-scale tests.
- Develop bases for a calculation model for the prediction of realistic fire performance of electrical cables, in some key constructions, based on the results of small-scale tests on materials.
- Investigate the validity of models comparing the output from the models with realistic design fire test data.

The experimental work was carried out at different scales and linked by correlation and fire modelling studies, which could form the scientific foundations for standards upon which the fire performance measurements can be based. There are four test-scales ranging from small material samples to real scale mock cable installations:

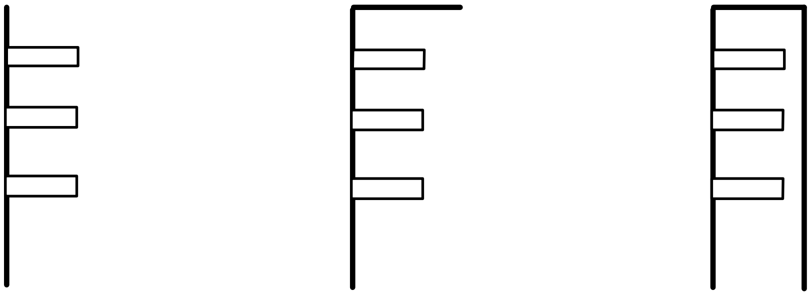
1. Real-scale scenario tests carried out on model electric cable installations
2. Full-scale standard tests carried out on cable trays (based on IEC 60332-3)
3. Small-scale tests on cables carried out in a cone calorimeter
4. Small-scale tests on materials carried out in a cone calorimeter

REVIEW OF EUROPEAN INSTALLATIONS AND CABLE SELECTION

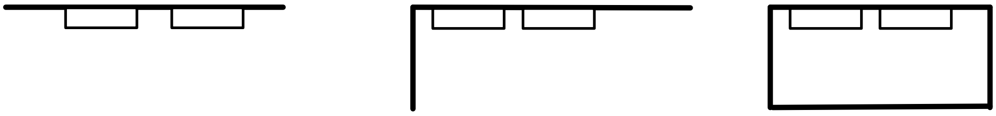
A study was performed to investigate the main cable installation practices used in Europe, such as types of: cable trays, cables, cable constructions, cable materials, loading levels and types of fixing, etc. This determined the major installation scenarios for study to be Power plants, Vehicles (trains, ships and aircraft), Tunnels and Occupancies (e.g. under-floor voids, ceiling voids and riser shafts). Each scenario revealed specific characteristics that relate to configuration, type and amount of cable used. From this study a set of cables were also identified for use throughout the project. These cables were defined as “data base cables” and were used in the real scale tests and for the full-scale test, the small-scale cable and the material test and the test results utilised in the modelling work.

REAL-SCALE SCENARIOS

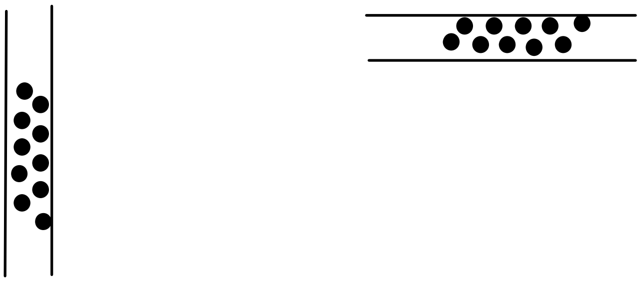
The review identified several vertically and horizontally orientated cable installations and a number of test configurations were selected which were representative of these. In addition to orientation a further division is made based on whether or not there is thermal feedback from an adjacent surface (wall, floor, and ceiling). Hence three subdivisions can be made, namely open, semi-closed and closed. The closed configuration can be tested with or without ventilation. Figure 1 illustrates the selected test configurations that can represent scenarios in each of the four studied installation scenarios.



horizontal test configurations



vertical test configurations



“void” test configuration

Figure 1: Real Scale Scenarios

Preliminary tests were performed and analysed at SP to compare the different configurations and optimise the final test configuration(s) for the data base tests which were performed on selected cables. During the preliminary test series, several heat source programmes were investigated. The ignition source used in all programmes was a diffusion burner because this is more representative of a real ignition source than the highly directional premixed gas burners used in IEC 60332-3 tests. The latter are convenient to use in testing as the flame energy is focused on the specimens but such sources are only very rarely seen in real fires. The following orientations and configurations were tested.

- Open horizontal configuration
- Semi-closed horizontal configuration
- Closed horizontal configuration with one side wall partially closed
- Closed horizontal configuration without side walls (with and without ventilation)
- Open vertical configuration
- Semi-closed vertical configuration
- Closed vertical configuration (with and without ventilation)
- Vertical void configuration
- Horizontal void configuration

These tests led to the establishment of one horizontal and one vertical configuration for testing the real scale data base cables, which are illustrated in Figures 2 and 3. Both test configurations utilised a stepwise heat source programme.

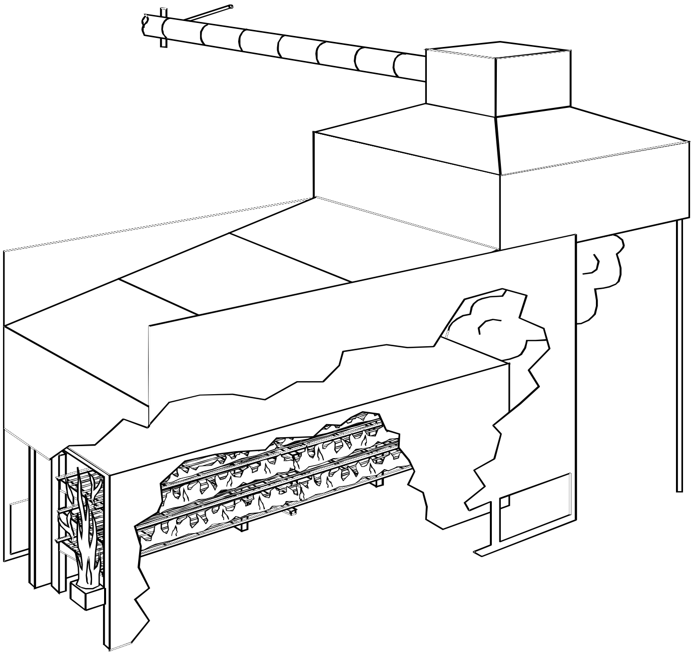


Figure 2: Schematic of Horizontal Set Up

The most efficient horizontal test set up (shown in Figure 2) has:

- Closed horizontal configuration
- No side walls in contact with cable trays
- No ventilation
- Heat source programme (40kW-100kW-300 kW)
- Three cable trays installed

The closed scenario, with no forced ventilation, is necessary in order to distinguish between the cables in the database. Cable mounting in highly ventilated areas is uncommon in Europe; thus, a non-ventilated scenario was chosen. A stepwise heat source programme permitted distinctions to be made between different cable groups.

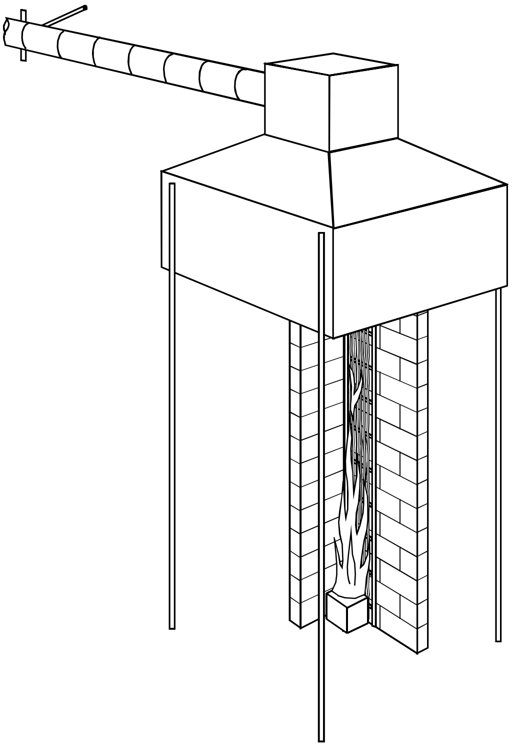


Figure 3: Schematic of Vertical Set Up

The most efficient vertical test set up (shown in Figure 3) is:

- Semi-closed vertical configuration (corner situation)
- No ventilation
- Heat source programme 3 (40-100-300 kW)
- One cable tray installed

The semi-closed, non-ventilated scenario was chosen here, since most cables are not mounted in highly ventilated areas. A stepwise heat source programme permitted distinctions to be made between even more cable groups. The vertical scenario is considered more severe than the horizontal and the majority of the real scale tests were tested in this scenario.

Table 1 shows how some of the cables tested performed in the real scale tests in terms of the flux regime under which the cable trays were consumed.

Cable	**Horisontal Scenario**			**Vertical scenario**		
	40 kW	**100 kW**	**300 kW**	**40 kW**	**100 kW**	**300 kW**
1	0	yes	N/A	0	yes	N/A
2	0	0	yes-	0	0	yes
3	yes	N/A	N/A	0	yes	N/A
4	0	yes-	yes	0	yes	N/A
5	0	yes-	yes	0	yes	N/A
6	0	yes-	yes-	0	yes-	yes-
7	yes	N/A	N/A	yes	N/A	N/A
8	yes-	yes	0	yes-	yes	N/A
9	yes	N/A	N/A	yes	N/A	N/A
10	yes-	yes-	yes	yes	N/A	N/A

Table 1: Flame Spread Characteristics in Real Scale Tests

Key to Table 1

yes : flame spread that continues to the end of the cable tray
yes- : flame spread that decreases after a certain period
N/A : Not applicable, since flame spread already occurred at the previous heat source level and the burner heat output was not increased to this level
0 : No flame spread at this level

Heat release rates and smoke release rates as well as toxic gas measurements were made in these tests and additional parameters such as the FIGRA index, which gives a measure of the size and growth rate of a fire and expresses a big and fast growing fire as the most dangerous, were determined. FIGRA is calculated as the peak HRR (30-s average) divided by the time to the peak. The SMOGRA (smoke growth rate index) index is calculated in the same way as the FIGRA index. The SPR vector is 30-s averaged and the index is calculated as peak SPR divided by the time to the peak. Table 2 presents some of the values calculated over the complete test and all burner levels.

Cable	**Scenario**	**Time to ignition (s)**	**Peak HRR TOT (kW)**	**THR (MJ)**	**Peak SPR TOT (m^2/s)**	**FIGRA (kW/s)**	**SMOGRA (cm^2/s^2)**
1	V	241	284	182.7	6.5	0.234	82.5
2	V	141	195	97.5	6.9	0.144	67.6
3	V	49	377	91.9	5.5	0.675	114.1
4	V	257	223	70.9	8.6	0.335	142.6
5	V	153	304	118.5	0.5	0.473	7.9
6	V	81	158	91.0	4.9	0.116	39.9
7	V	29	374	57.3	6.4	2.173	213.7
8	V	49	203	65.0	9.4	0.399	216.2
9	V	30	466	54.9	7.3	3.526	498.1
10	V	101	339	74.5	0.5	0.982	10.3
1	H	145	675.1	460.0	28.1	0.691	222.8
2	H	325	157.9	70.3	6.0	0.100	62.3
3	H	53	902.2	333.0	27.5	1.661	0.5
4	H	110	202.0	106.7	5.5	0.414	141.9
5	H	89	362.6	197.1	1.9	0.580	13.6
6	H	98	225.6	139.5	5.0	0.194	80.7
7	H	45	501.9	111.9	23.5	1.904	904.1
8	H	45	189.3	65.0	6.0	0.504	106.9
9	H	33	301.4	83.5	17.4	3.434	618.4
10	H	61	131.4	63.4	0.8	0.678	6.3

Table 2: Parameters Measured in some of the Real Scale Tests

FULL-SCALE TESTING

The full-scale testing in the FIPEC programme involved the following tasks:

- Implementation of modern measuring techniques on a standardised test method for cables.
- Sensitivity study of the chosen method with respect to mounting, burner level, thermal boundaries and air flow.
- Development of the test method and procedure.
- Examining the performance of data base cables.

The IEC 60332-3 test is probably the most important fire test for cables in Europe and as such was the natural candidate for enhancement to facilitate on-line measurement of heat and smoke releases and ignitability. Oxygen consumption calorimetry was used for measuring heat release rates, and smoke release was measured using a dynamical method with photodiodes because both these techniques are well established. If correlation studies were to be carried out between full and small scales, it was important to use the same measurement techniques for both scales of testing.

Examination of the real scale test results showed that the FIGRA and SMOGRA values determined in the horizontal and vertical tests correlated, and this gave good confidence that a full-scale vertical-oriented test, based on IEC 60332-3, could be used as a sound basis for assessment of cable fire performance in all orientations.

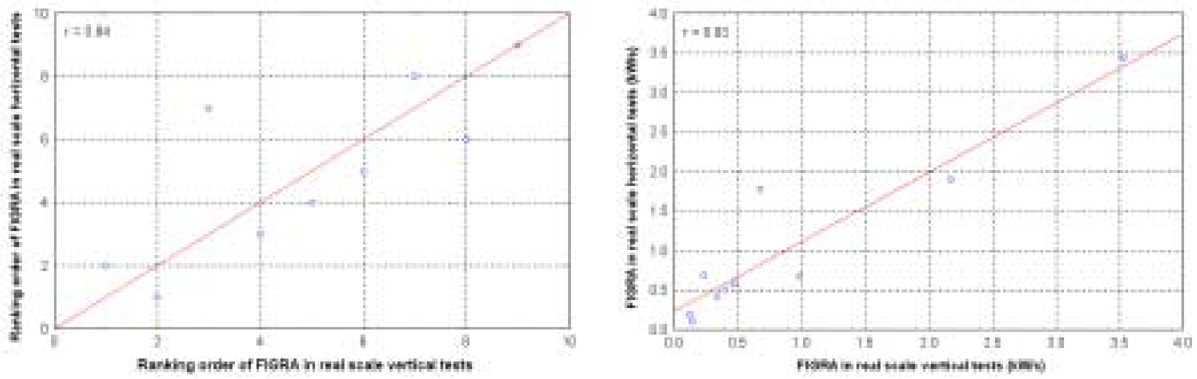


Figure 4: Ranking and Parameter Correlations Between Horizontal and Vertical Real Scale Tests

The major modification to the equipment itself is to the exhaust duct. A duct insert has to be included in a straight section of the existing extraction duct to house a bi-directional probe and thermocouple (flow measurement), the gas sampling probe and the smoke measurement system and photodiodes assembly, and thermocouple (smoke measurement).

Two studies have been performed to investigate flow measurement in the chamber. These were measurement of the response time of the HRR measurements and investigation of the flow distribution through the apparatus by means of a CFD (computational fluid dynamics) model.

It was necessary to study the effects of test variables on the cable test performance in order to develop the data base cable test protocol. The impact of the several parameters on the IEC 60332-3 cable tests performance was studied. These parameters included:

- loading, bundling, grouping, and spacing of cables on the ladder,
- burner output (several levels),
- presence of thermal boundaries,
- burner position e.g. angle between burner and cables,
- level of ventilation through the enclosure

Almost all of the mounting variables, including the presence of the thermal boundary, had significant influence upon the fire characteristics of the cables but increasing burners levels from the conventional IEC 60332-3 level had little effect on performance. The IEC 60332-3 burner gave a considerably more severe test than the diffusion burner and a higher energy diffusion burner would be required to generate a similar level of ignition. This demonstrates why larger diffusion flames were needed for the real scale tests but it also indicates that the IEC burner is better suited for the full-scale tests

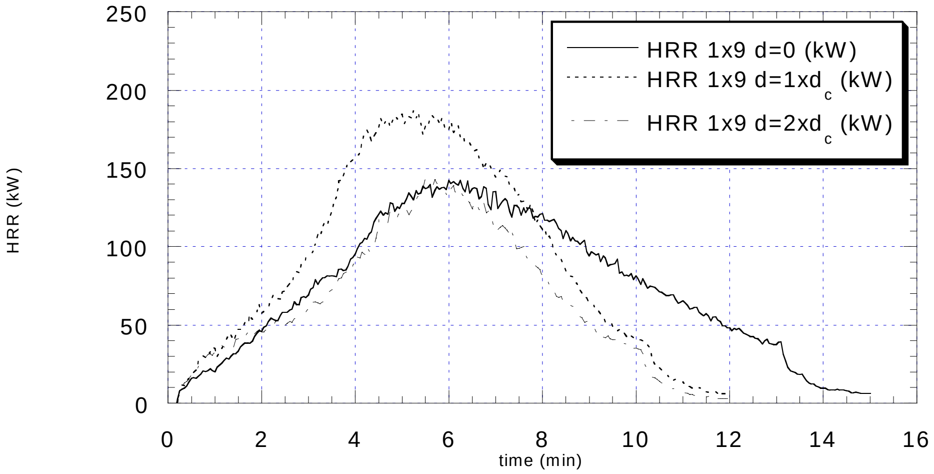


Figure 5: Comparison of Cable HRR Mounted With and Without Spacing

Figure 5 shows that spacing this cable with a distance equal to one cable diameter is certainly more severe than testing without spacing. Increasing the spacing to twice the cable diameter leads to a less severe test configuration.

The preliminary studies demonstrated that two different test protocols should be used for the database tests. These are both based on the IEC 60332-3:

Scenario 1

This test procedure is similar to the IEC 60332-3. It uses the 20.5 kW burner and differs from the IEC 60332-3 method in two major ways:

a) The airflow into the IEC 60332-3 test chamber is increased from 5000 l/min to 8000 l/min in order to improve the response of the heat release measurement and the available oxygen for the combustion.

b) All cables with a diameter greater than 5 mm are mounted individually with a spacing of one cable diameter between each cable. Cables with a diameter less than 5 mm are mounted in bundles (non-twisted) of 1 cm diameter with a 1 cm distance between each bundle.

Scenario 2

This second test procedure uses the IEC 60332-3 burner with an increased heat release level equal to 30 kW. A non-combustible backing board is mounted on the rear of the cable ladder. The airflow into the test chamber and the cable mounting procedure is identical to scenario 1.

Full Scale Test Repeatability and Reproducibility Study

Before the main data base tests were carried out a number of cables were tested to assess repeatability and reproducibility of the technique within the 3 labs. Figure 6 shows the good repeatability levels of HRR measurement.

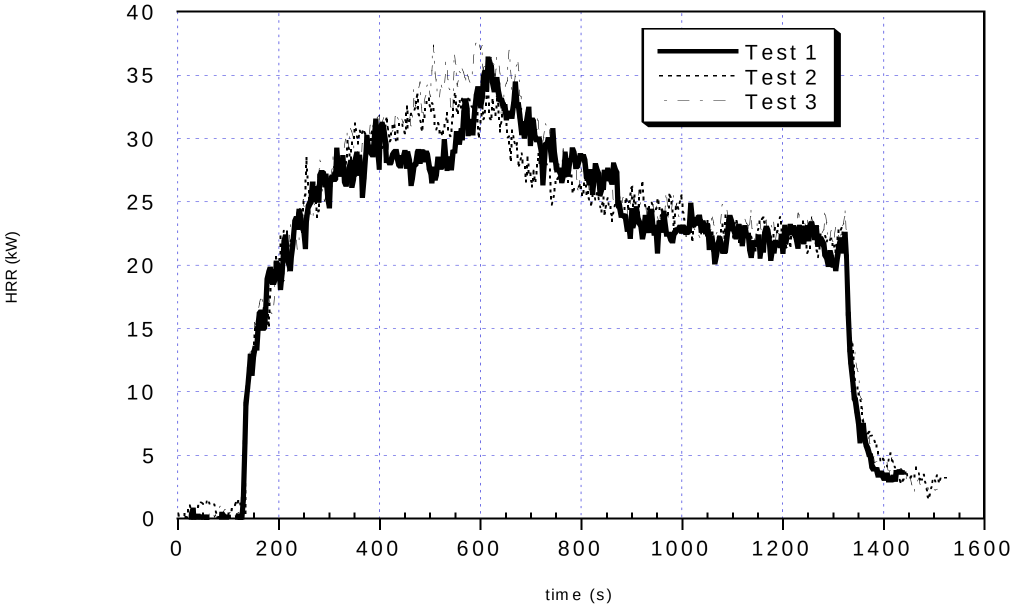


Figure 6: Repeatability of Heat Release Rate for Full-Scale Tests

Figure 7 shows that the reproducibility of HRR is good with differences between peak heat release rate are less than 5 %. Figure 8 shows the reproducibility for the SPR. In this graphs we can observe the more than acceptable levels of reproducibility. A small drift could be seen at one laboratory. This was subsequently rectified before the data base tests were performed.

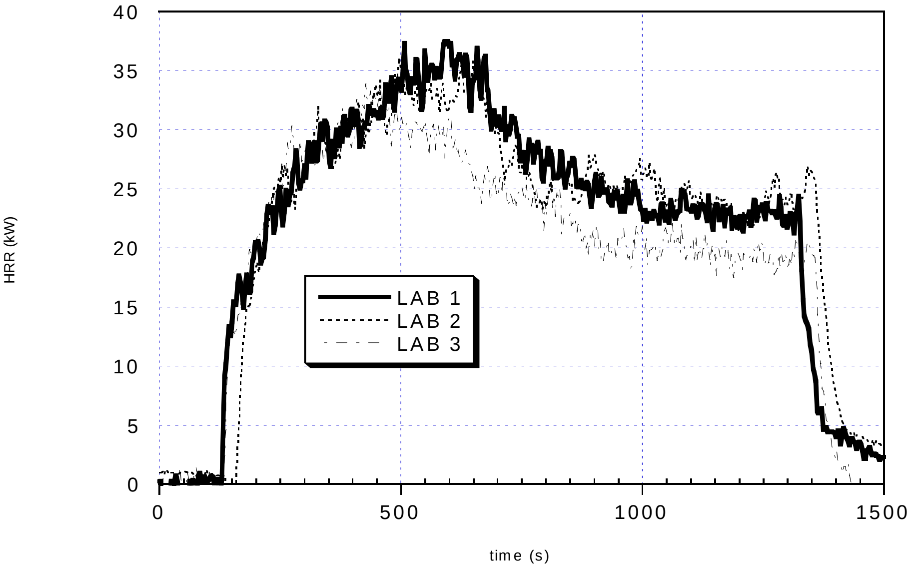


Figure 7: Reproducibility of Heat Release Rate for Full-Scale Tests

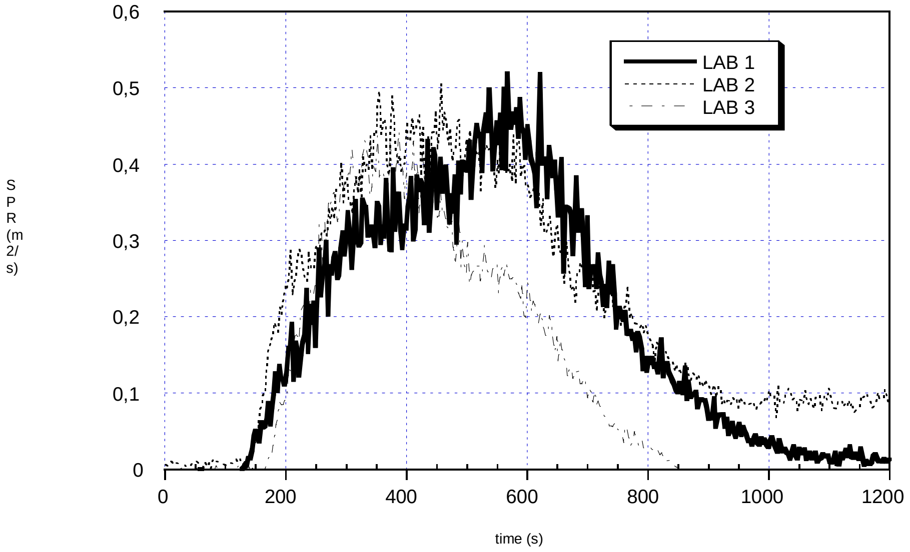


Figure 8: Reproducibility of Smoke Production Rate for Full-Scale Tests

The results of these tests revealed that the reproducibility and repeatability of the proposed test arrangement is acceptable and certainly comparable with other fire tests. The smoke production rate reproducibility data is better than most data available from other smoke studies. These results show that the repeatability and reproducibility of this technique exceeds that of the SBI test being used by the EC for classifying other construction products. This was confirmed by a final RR within the three laboratories with triplicate testing of 5 combinations. Not one change in fail/pass criteria was observed within the three laboratories.

Full-Scale Data Base Testing

These tests showed both procedures to be effective in differentiating between cables with different fire propagation and heat release characteristics. Figure 9 shows plots of 4 types of cable performance in scenario 1 tests. One cable develops a high heat release soon after the test onset. A second cable develops a high peak at approximately 2000 seconds into the test. A third shows negligible HRR until 2000 seconds and a fourth shows no significant heat release throughout the test.

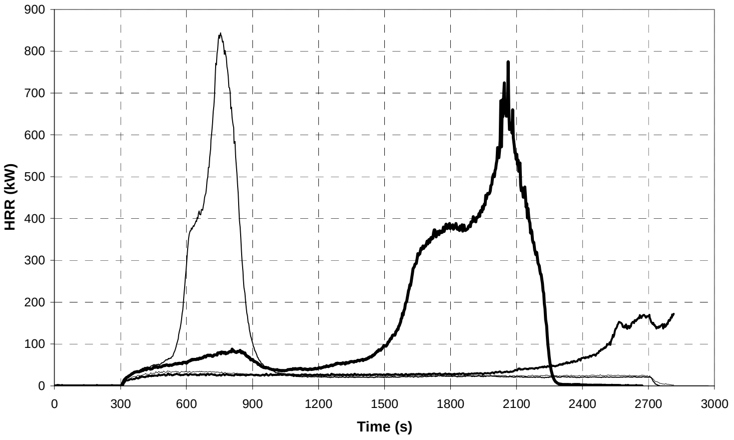


Figure 9: Typical HRR in Scenario 1 Tests Showing Four Types of Performance

Figure 10 shows cable performance in scenario 2 tests. Again one cable reaches peak heat release very quickly. A second shows a slower development and the microstructure of the curve shows different components of the cable contributing to fire development. A third shows steady growth for the duration of the test and the fourth shows very little heat release throughout this more severe test.

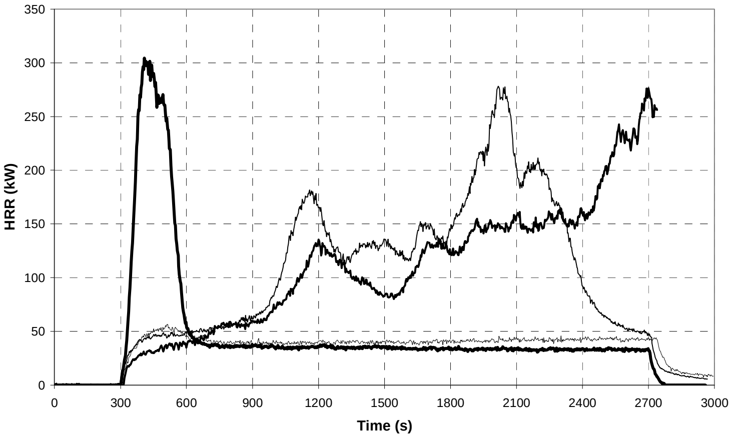


Figure 10: Typical HRR in Scenario 2 Tests Showing Four Types of Performance

SMALL SCALE CABLE TESTS TO DETERMINE THE ESSENTIAL PARAMETERS

Cables present non planar surfaces in cone calorimeter testing and an investigation was required to ascertain if different parts of the specimen surface would experience significantly different heat flux levels during testing, as the heat flux transmitted to any point under the cone falls off with vertical distance from the cone base plate. Small cut cable specimens also allow the escape of degradation products from the ends of the cables and do not allow thermal conduction of heat along cable conductors. These phenomena may not occur in real cable fires and were investigated prior to testing the FIPEC database cables.

As study of the heat flux profile under the cone heater was undertaken using free standing heat flux meters. The measured fall off in measured heat flux with distance from the cone base plate is shown in Figure 11. This shows that a specimen would see only small variations in incident heat flux levels for specimens with surface height variations less than 10 mm. Work carried out by Lukas [5] using heat flux meters housed in aluminium trays also measured the variation of heat flux with distance from the cone base plate. This showed that for an incident heat flux of 25 kW/m^2 at the specimen surface the heat flux at the bottom of a 50 mm aluminium specimen tray is only 1% lower. These empirical results of Lukas show that the likely heat flux differences experienced across the surface of a non planar specimen like a cable would be even less than measured in the above free standing heat flux meter studies. It was therefore considered that the effect of non-planar surface would have minimal effect on incident heat flux levels on cable performance in the cone calorimeter tests.

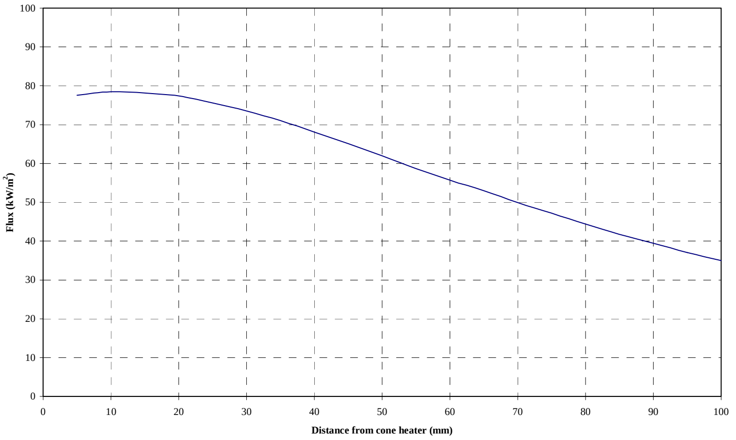


Figure 11: Variation of heat flux at centre position with distance from cone base plate

A second test series was directed to investigate the influence of loss of pyrolysis products from the ends of the cables and the effects of conduction through the cable conductors. The first was investigated by testing 100 mm long sections of cable both with open and sealed ends (using conventional ISO 5660 edge frames). The latter was studied by testing longer sections of cables (200 mm) in such a way that only the central 94 mm of the cable span was exposed to the heat flux. The exposed area in this 200 mm cable set was similar to that of the 100 mm set because the ISO 5660 edge frame also has a 94 mm exposure window.

Seven cables were then tested at 25 kW/m^2 and at 50 kW/m^2 in three sets:

1. 100 mm long sections of cable with ends open, tested with the edge frame ("open")
2. 100 mm long sections of cable with ends sealed, tested with the edge frame ("sealed")
3. 200 mm long partially shielded to have the same specimen exposure length as 1 & 2

The test results can show that the effect of end sealing cables:

- has little influence on the times to ignition for all cable sizes, cable constructions and material combinations,
- has little effect on the heat release from the cables,
- gives more repeatable test results especially when the cables are being tested at low heat fluxes.

The effect of using extended cable specimens and sealing and shielding the cable ends,

- does not affect times to ignition,
- considerably reduces the heat release generated in early stages of the burn,
- extends the burn period extensively,
- gave less repeatable tests than the non shielded cables,
- changes the burning area during the test due to flow of thermoplastic materials.

It was concluded that the most repeatable procedure for the database cable tests would be using 100 mm long end sealed cables.

A testing protocol was prepared and repeatability and reproducibility experiments were carried out on several cables tested in accordance with it in the 4 laboratories. Both were shown to be good.

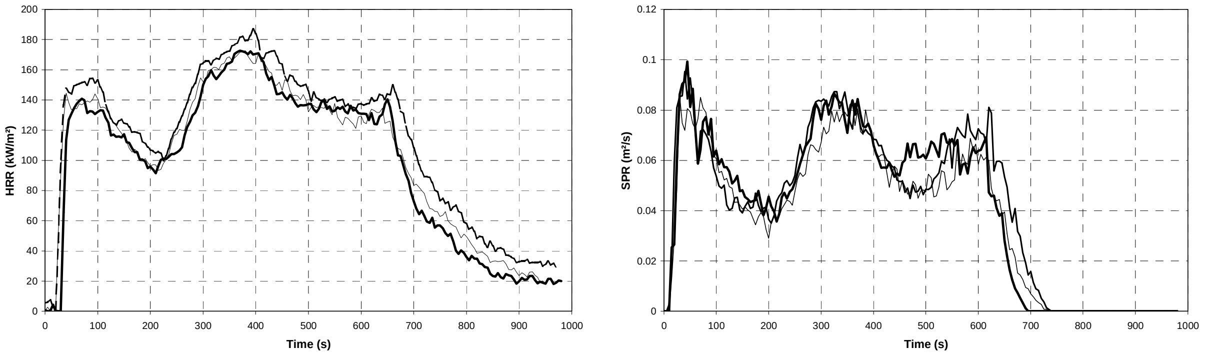


Figure 12: Repeatability of HRR and SPR for Cone Calorimeter Tests

Figure 12 shows the excellent repeatability data for heat release rate and smoke production rate whilst Figure 13 gives the reproducibility data for the most complex cable in the study. Note the time duration of the test which confirms the excellent results.

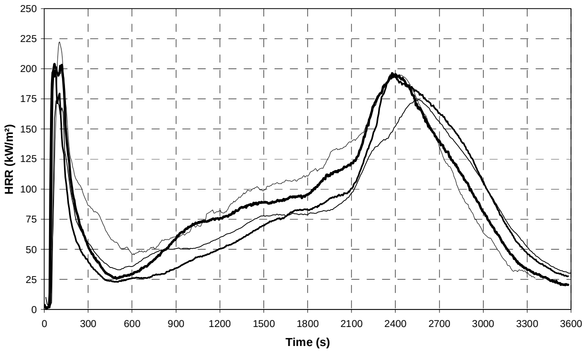


Figure 13: Reproducibility of HRR for Cone Calorimeter Tests

The database cables tested showed a variety of behaviours at different heat fluxes depending upon the cable composition and construction. Figure 14(a) shows results of testing cables with different fire properties at 50 kW/m^2 in the cone calorimeter. One cable shows a very fast peak and then ceases to burn; a second gives a low initial peak and then continues to burn with a low heat release rate. The other two show similar behaviours but at different intensities. One gives an initial peak heat release rate of 200 kW/m^2 and subsequent peaks up to 350 kW/m^2 as the different cable components become involved in the burn. Figure 14(b) shows similar performances for cables tested at 75 kW/m^2.

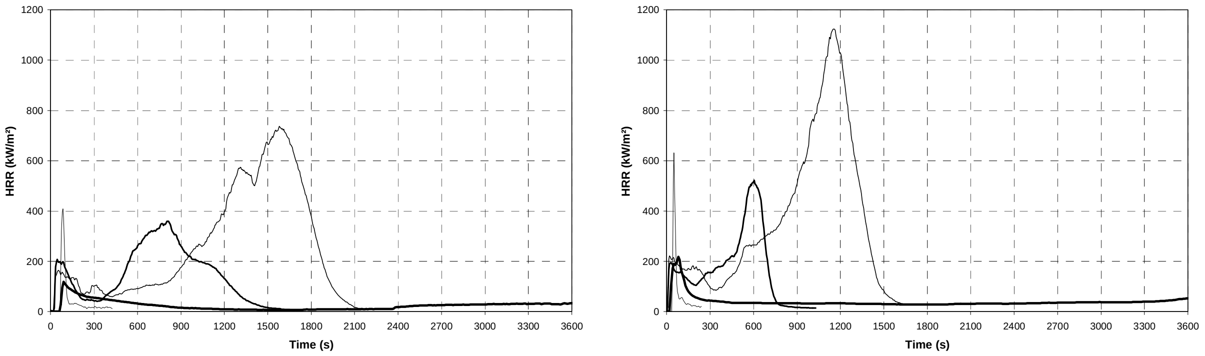


Figure 14: HRR from Different Cables in Cone Calorimeter at 50 and 75 kW/m^2

The technique also proves to be very good at differentiating the properties of cable sheath and cable insulation materials as shown in Figure 15.

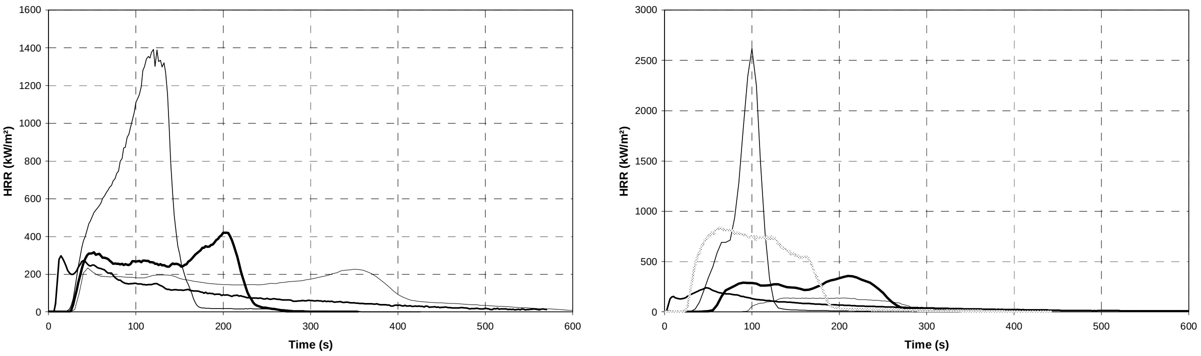


Figure 15: HRR from Different Cable Sheath and Insulation Materials tested in the Cone Calorimeter at 75 kW/m^2

CORRELATION BETWEEN TESTS PERFORMED AT DIFFERENT SCALES AND MODELLING WORK

The type of links between the testing levels can be distinguished in the following categories. Some of them will be covered in the following paragraphs, other will follow in specific and more detailed publications.

1. Ranking order correlations between different levels of testing,
2. Correlations between parameters obtained in the different levels of testing,
3. Numerical or Analytical models for flame spread based on thermal flame spread theories,
4. CFD flame spread models.

Ranking Order Correlations

Ranking order correlation is the simplest way to investigate whether specific types of tests correlate which each other. According to the risk envisaged the materials are ranked using one or sometimes more parameters. By means of a statistical package the degree of correlation between the tests can then be investigated for the specific parameter or risk studied. In the following paragraphs some of the different ranking order correlations within FIPEC are discussed.

In order to validate the full-scale test against the real-scale tests a number of ranking order correlations was first performed. For this the Spearman ranking order correlation coefficient was used. Ranking order correlation of flame spread, ignition, peak HRR, FIGRA, THR, peak SPR, SMOGRA and TSP between the real scale testing and the two procedures in the IEC 60332-3 test. Only the major findings are given here.

The ranking correlation between IEC scenario 1 and vertical real scale is good for heat release parameters and very good for the SMOGRA index (see Figure 16).

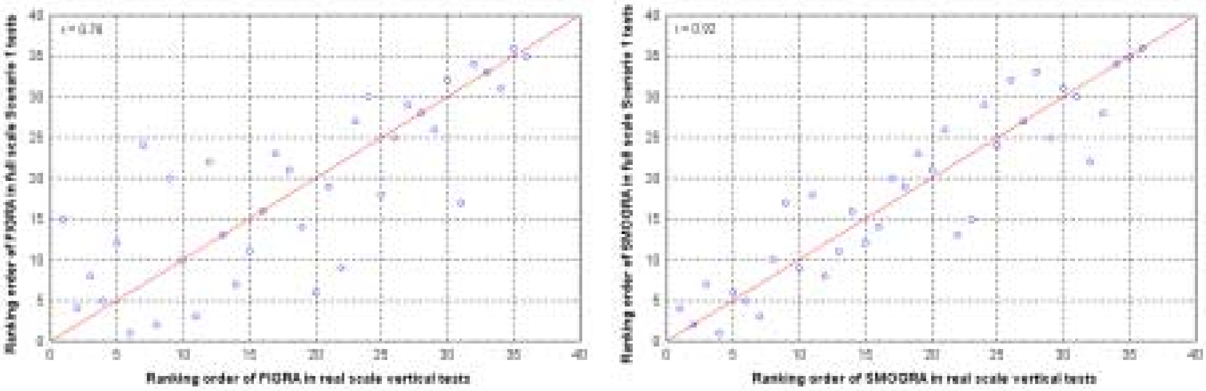


Figure 16: Spearman Ranking Order Correlation Between FIGRA IEC 60332-3 Scenario 1 and FIGRA Real-Scale Vertical Scenario, and the SMOGRA Correlation in the Same Tests

IEC 60332-3 scenario 1 and horizontal real scale test results correlate very well both for heat release and smoke parameters, although there are fewer points, see Figure 17. This is an important result as it proves the IEC 60332-3 scenario 1 can be used to assess cables installed horizontally as well as those installed vertically.

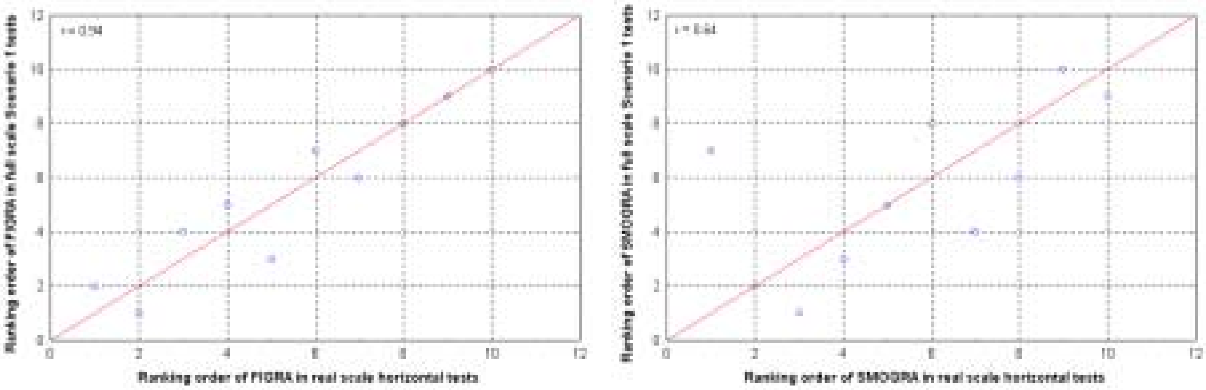


Figure 17: Spearman Ranking Order Correlation Between FIGRA IEC 60332-3 Scenario 1 and FIGRA Real-Scale Horizontal Scenario, and the SMOGRA Correlation in the Same Tests

The IEC scenario 2 and vertical real scale tests also correlates well, both for heat release and smoke parameters - see Figure 18.

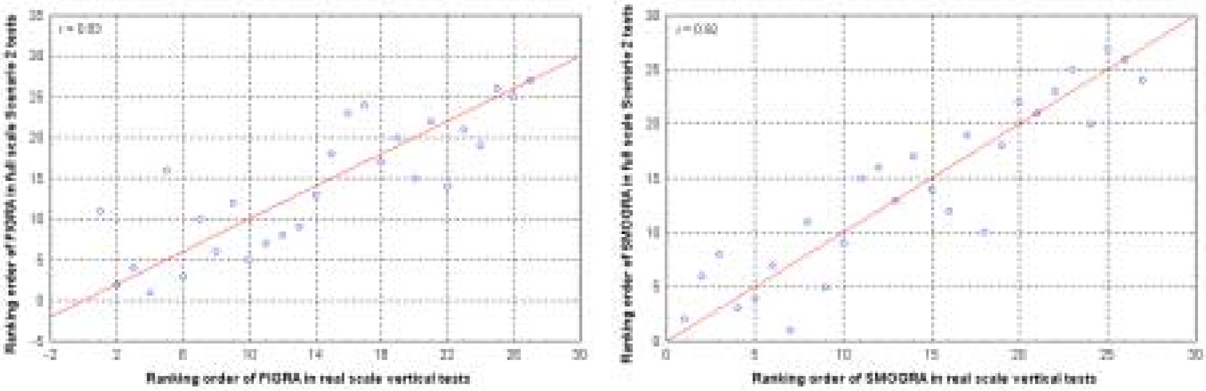


Figure 18: Spearman Ranking Order Correlation Between FIGRA IEC 60332-3 Scenario 2 and FIGRA Real-Scale Vertical Scenario and the SMOGRA Correlations in the Same Tests

The correlation between IEC60332-3 scenario 2 and horizontal real scale test is not quite as good as the above cases, despite the smaller number of points, see Figure 19. This is because scenario 2 is more severe and hence correlates better with the vertical real-scale tests which are more severe than the horizontal real-scale tests.

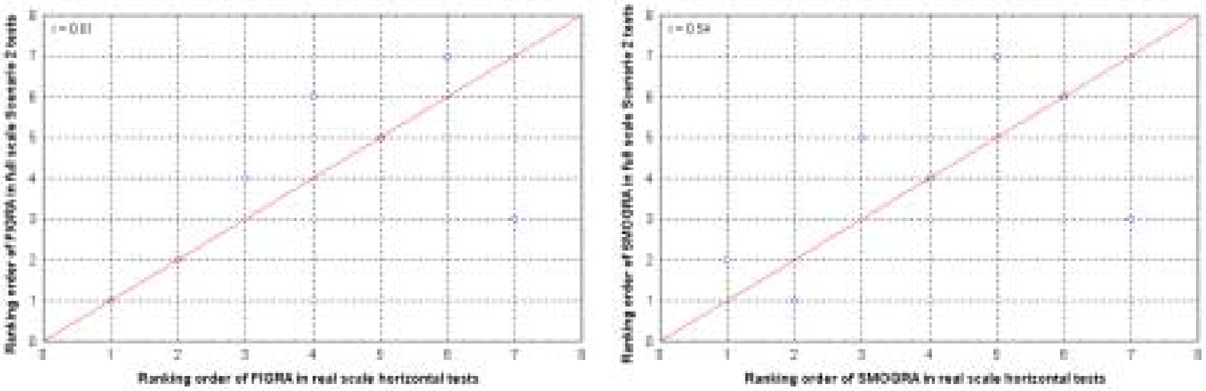


Figure 19: Spearman Ranking Order Correlation Between FIGRA IEC 60332-3 Scenario 2 and FIGRA Real-Scale Horizontal Scenario And the SMOGRA Correlation in the Same Tests

Parameter Correlation

In this case the measured parameters in the different test levels are correlated with each other. A first level can be to investigate linear curve fitting between the parameters by simple linear regression. Another level is to express a specific parameter in one testing scale as a function of different parameters of the other testing scale. In this case a more complex curve fitting is necessary. Possible correlation levels in FIPEC are given below.

The linear correlation between real-scale and full-scale confirms what the ranking order study predicted, there is indeed a good correlation between the two scales. It is interesting to note that in almost all cases the FIGRA and SMOGRA indices give better linear correlation than the peak heat release and peak smoke production values alone.

The linear correlation between IEC 60332-3 scenario 1 and vertical real-scale tests is very good for both heat release and smoke parameters. As an example the FIGRA correlation and the SMOGRA correlation is plotted in Figure 20.

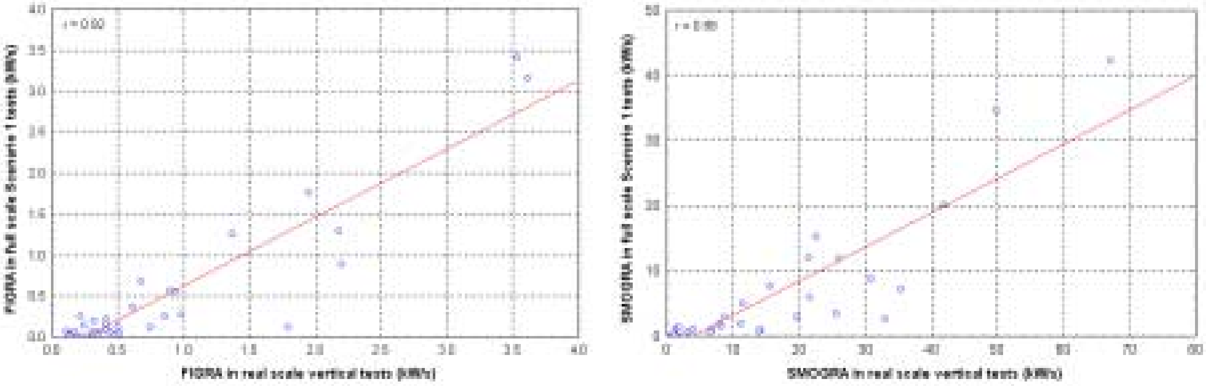


Figure 20: Pearson Linear Correlations: FIGRA IEC 60332-3 scenario 1 and FIGRA Vertical Real Scale and the SMOGRA Correlation for the Same Tests.

IEC 60332-3 scenario 1 and horizontal real-scale tests also have a very good linear correlation (see Figure 21). Again this confirms the strong link between the IEC 60332-3 tests and real scale scenarios.

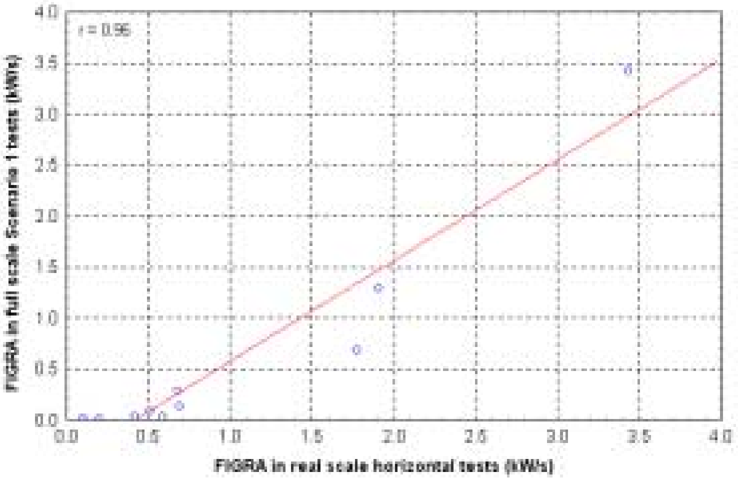


Figure 21: Pearson Linear Correlation: FIGRA IEC 60332-3 Scenario 1 and FIGRA Horizontal Real Scale

For IEC 60332-3 scenario 2 and vertical real-scale tests the linear correlation is very good for smoke parameters but only relatively good for heat release parameters. This comes partly from the fact that the cables tested in the IEC 60332-3 scenario 2 were mostly high-performance cables that did not burn much in scenario 1. The results are therefore covering a smaller range, making good correlation more difficult.

Results determined in numerical and analytical modelling and in CFD flame-spread models developed within this programme will be reported in subsequent publications.

CONCLUSIONS

Much of the FIPEC project work is now concluded and full scale testing protocols based on modified IEC 60332-3 have been developed and validated. Repeatability and reproducibility work has shown that these test procedures are highly repeatable and reproducible. The results of the tests carried out on the data base cables also 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 allows 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.

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. Correlations are being examined between these results and results of the IEC 60332-3 test on data base cables.

Both of these scales of 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 and CEN, and to the European Cable Making Industry to assist development of better assessment methods.

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