Determination of design fires for cables

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Abstract

FIPECMATCH is a cloud computing software for matching the new HRR small-scale cable test to the HRR small-scale cable test of FIPEC's database. This package works by setting up two HRR filters, which would be able to select the most similar HRR pattern stored in the FIPEC's database. This thesis writing will discuss the filter process in details together with the running results. The advantage of this work is aimed for exploitation the variety of FIPEC's database to be the reference resource. The HRR of cable testing in full-scale would be achieved by the HRR of small-scale cable test by means of HRR comparison and matching rather than mathematical correlations.

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Disclaimer

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Abstract

FIPECMATCH is a cloud computing software for matching the new HRR small-scale cable test to the HRR small-scale cable test of FIPEC's database. This package works by setting up two HRR filters, which would be able to select the most similar HRR pattern stored in the FIPEC's database. This thesis writing will discuss the filter process in details together with the running results. The advantage of this work is aimed for exploitation the variety of FIPEC's database to be the reference resource. The HRR of cable testing in full-scale would be achieved by the HRR of small-scale cable test by means of HRR comparison and matching rather than mathematical correlations.

บทคัดย่อ

ฟิเพคแมทช์ คือ โปรแกรมคอมพิวเตอร์ที่ประมวลผลบนหน่วยความจำกลางเครือข่าย สำหรับการจับคู่อัตราการปล่อยความร้อนจากการเผาไหม้ของสายไฟในการทดลองขนาดเล็ก ระหว่างผลการทดลองใหม่ กับ ผลการทดลองที่จัดเก็บไว้ในโครงการฟิเพค โปรแกรมนี้ทำงานโดยอาศัยหลักการตัวกรองอัตราการปล่อยความร้อนจากการเผาไหม้จำนวน ๒ ชั้น ซึ่งสามารถเลือกหารูปแบบอัตราการปล่อยความร้อนที่มีความคล้ายคลึงกันมากที่สุดได้ วิทยานิพนธ์ฉบับนี้ จะอธิบายถึงหลักการทำงานของโปรแกรม ตลอดจนผลลัพธ์ของการประมวลผล ประโยชน์ที่คาดว่าจะได้รับ คือ การนำฐานข้อมูลของโครงการฟิเพคมาใช้เป็นมาตรฐานเทียบเคียง ในการทดสอบผลิตภัณฑ์สายไฟที่ผลิตขึ้นมาใหม่ ทั้งนี้ หากว่า ผลการทดลองขนาดเล็ก ของสายไฟที่ผลิตใหม่ มีความคล้ายคลึง กับ ผลการทดลองในโครงการฟิเพคแล้ว ผลการทดสอบตัวอย่างในการทดลองขนาดใหญ่ สามารถคาดคะเนได้ในเชิงของการเปรียบเทียบ มากกว่าที่จะเป็นการคาดคะเน โดยใช้ความสัมพันธ์ทางคณิตศาสตร์

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1. List of abbreviations

CHRISTFIRE	Cable heat release, ignition and spread in tray installations during fire
FIGRA	Fire growth rate
FIPEC	Fire Performance of Electric Cables
HRR	Heat release rate
$HRR_{Ave\ T40}$	Average heat release rate at the time 40th second
HRR_{T40}	Instant heat release rate at the time 40th second
HRR N	Heat release rate of the new input
HRR N420	Heat release rate of the new input at the time 420th second
HRR N1400	Heat release rate of the new input at the time 1400th second
HRR S	Heat release rate of the item in the short list
HRR S420	Heat release rate of the item in the short list at the time 420th second
HRR S1400	Heat release rate of the item in the short list at the time 1400th second
N	Total number of time step in the comparison zone.
s	Second
SML_{AVE}	The average similarity (%)
SML_i	The instant similarity for each time step (%)
SML	The similarity
SML 420	The instant similarity at the time 420th second
SML 1400	The instant similarity at the time 1400th second
SP	Science Partner Technical Research Institute of Sweden
TTP	Time to the peak heat release rate
US.NRC	United States Nuclear Regulatory Commission

2. List of figures and tables

3. Introduction & Objectives

3.1 Introduction

Cables are one of the major combustible materials in premises, industrial facilities and nuclear power plants in particular. A Cable fire is an important hazard because the fire can propagate along the cable routes and therefore knowledge on cable fire characteristics is of a concern for fire safety engineering.

There have been a lot of attempts for the past decades to investigate the cable fire responds. CHRISTFIRE which is supported by U.S.NRC is an example of a cable fire study [1]. That project proposed the FLASH-CAT model to predict the heat release rate of an horizontal arrangement cable fires together with the extension of the model for vertical installation in a later study [2].

FIPEC which stands for “Fire Performance of Electric Cables” is another effort to categorize the safety standard for cables [3]. This project aims to develop a cable classification by proposing more scientific testing procedures, which are based on an IEC existing testing standard in order to compromise the familiarity of European community. The important feature of this project is that enormous experiments have been performed both small-scale and two full-scale scenarios. All data was collected and stored in the electronic format which is available for further exploitation.

This project focuses on taking advantage of the database of FIPEC by matching new cable heat release rate curves which are obtained by small scale testing in the cone calorimeter ISO 5660 [4], to the existing heat release rate curves in FIPEC’s database. This method leads to the corresponding heat release rate curve of full-scale testing in accordance with FIPEC’s procedure [5].

3.2 Hypothesis

Pyrolysis and fire propagation as well as heat release rate are extreme complex phenomena because there are many relevant factors, which affect the process. In the cable testing discipline, the type of cable and mounting pattern seem to be the crucial factor, which can alter the testing results. Furthermore, fire safety engineers call for the prediction of end-use scenarios, which are associated with multi types of cable arranged in arbitrary mounting. These complexities hamper the findings to predict cable fire characteristics accurately.

To tackle this situation, a full database obtained from many experiments seems to be another solution rather than mathematical equations. It is useful, that FIPEC project has provided various databases for both small scale testing and full-scale testing [3]. This database can be used as the reference for new type of cables.

This project stems from the hypothesis that if there is a tool, which is able to match the new small-scale cable fire curves to the existing small-scale cable fire curve database, the full-scale

testing of new cable is predictable relative to the full-scale result of the database. This hypothesis is based on the fact that if two materials give the similar result in the small scale testing, it should yield the same result when it is tested in the same full-scale test procedure regardless of its chemical compounds if mounting is done similarly and dimensions are rather similar.

3.3 Objectives

This project has the following objectives.

1. Set up pairs of cable fire curve between small-scale testing and full-scale testing performed by FIPEC and upload to cloud storage.

2. Develop the matching method between new cable fire curves and existing cable fire curves.

3. Create a website as the user interface to be the data exchanger between users and database.

4. Give HRR of the full-scale test by small scale cable test result which is matched to the corresponding small scale cable test result stored in database.

3.4 Limitation

This project focuses on the HRR matching software development as the main part of the study therefore there is an uncertainty whether this project would be success or not during the period of one semester. As a result, the experiments for new cable which should be used to complete the software validation will not be included in this project.

The validation method will be limited only in terms of logic comparison which means that FIPECMATCH should give the matching result only for the HRR of cables. If users put the HRR of other types of material or the HRR obtained by different procedures, the result should be mismatching.

To complete the validation, new cable HRR should be conducted and put into this software which the author aims to get further supports from cable manufacturers. FIPECMATCH still needs more validation to be accepted as the standard tool for fire performance assessment of electric cables.

4. Methodology

In this section, all details associated with the matching process will be explained. The overall process chart will be described as the first place followed by the support details for each step.

4.1 The overall process

Figure 1 illustrates the overall process in the form of schematic logic chart.

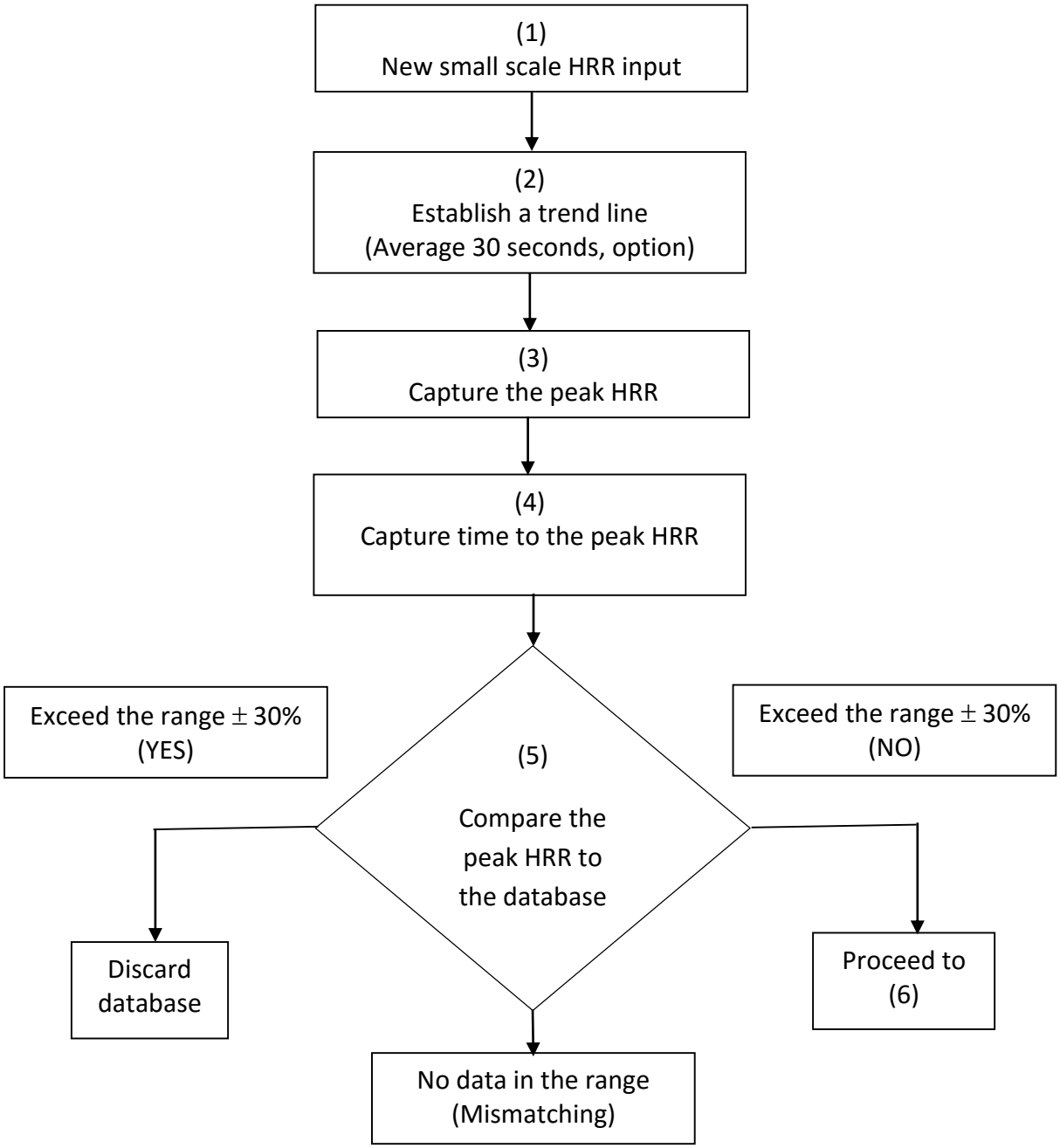

Figure 1 The overall process chart

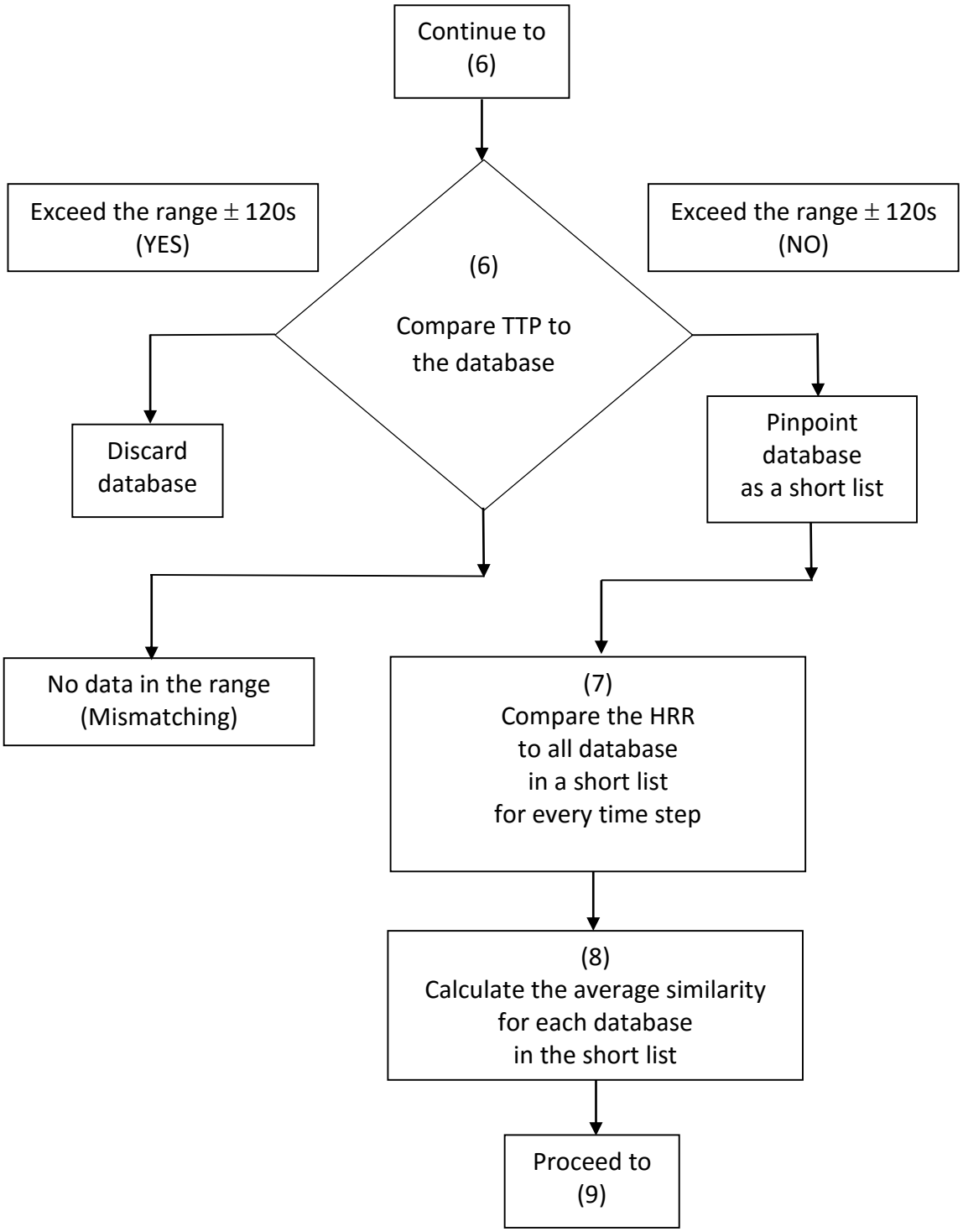

Figure 2 The overall process chart (Continue)

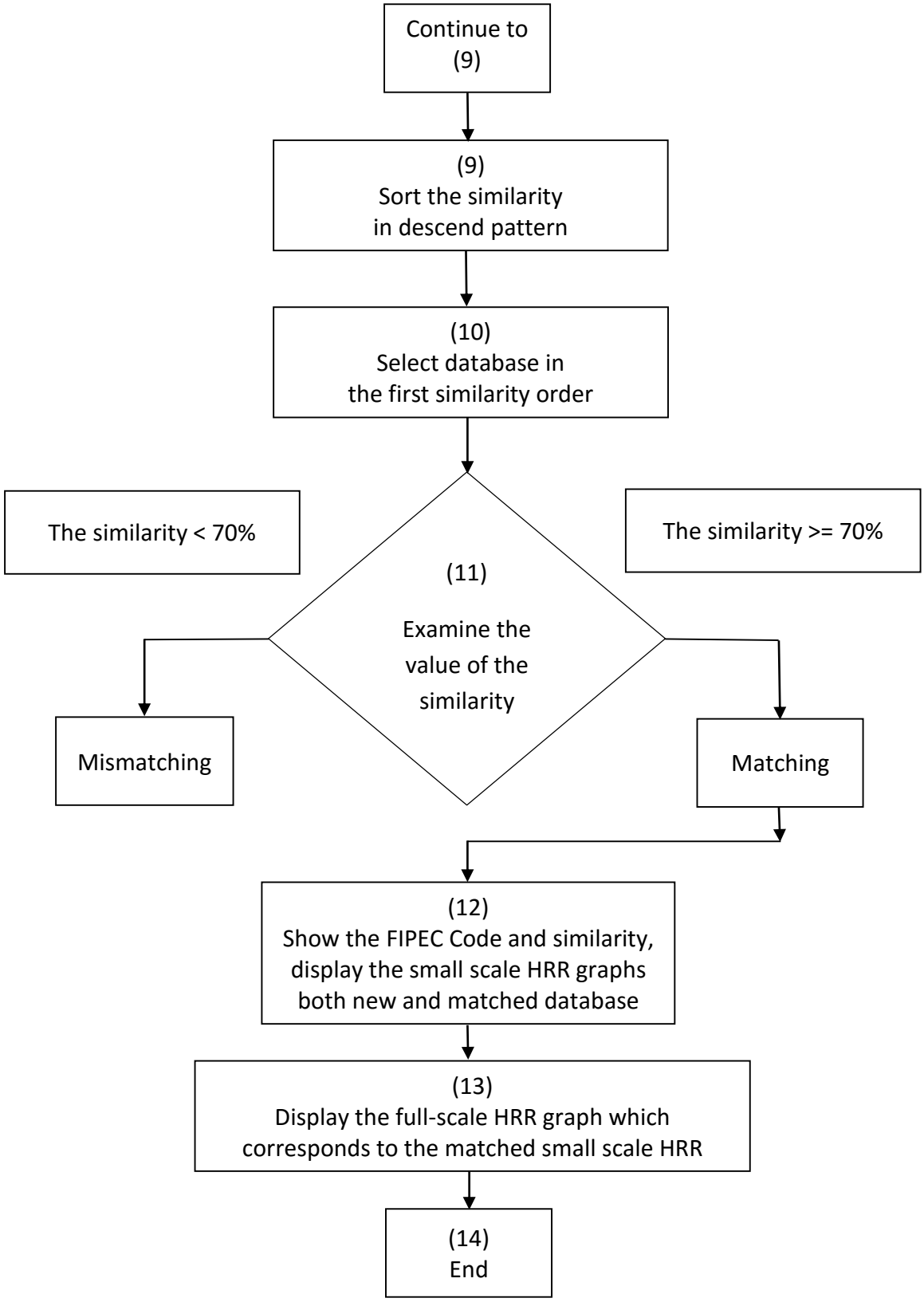

Figure 3 The overall process chart (Continue)

4.2 New small scale cable HRR input (1)

The FIPECMATCH's working process begins with receiving the HRR data of new small-scale cable test. This small-scale test must be performed in accordance with the ISO 5660 and the unit of the HRR must be kilowatt per square meter (kW/m^2) as well as the time step must be 5 seconds. Users just toggle the input sheet and then copy their HRR in order to paste on the FIPECMATCH's input sheet. Figure 4 shows the example of the input sheet and input instructions.

Time (s)	ISO 5660 HRR (kW/Sqm)	Instructions
0		1. Make sure the HRR unit is in kW/Sqm
5		2. Make sure the HRR is dumped every 5 seconds
10		3. Copy the HRR from the raw data sheet
15		4. Select row 2 to 10 in column B (ALL GREEN CELLS)
20		5. Right click while the pointer is on the selected area
25		6. Select "Paste special" option
30		7. Select "Paste values only" option
35		8. Proceed to Analyse New HRR button
40		
45		
50		
55		
60		
65		
70		
75		

Figure 4 The example of new small- scale cable HRR input sheet

4.3 Trend line (2)

If the user's HRR input is the raw HRR signal, a trend line or an average line is needed to be the representative line and readable line because the raw signal fluctuates very much, see Figure 5. This fluctuated graph cannot be interpreted to obtain the peak HRR and TTP. However, if the user's HRR input is already the average signal, it can be input to FIPECMATCH directly.

The trend line or the average line is achieved by calculating the average value over the certain range of time for example 30 seconds. The following equation depicts this explanation.

$$HRR_{Ave\ T40} = \frac{HRR_{T26} + HRR_{T27} + HRR_{T28} + \ldots + HRR_{T40} + \ldots + HRR_{T53} + HRR_{T54} + HRR_{T55}}{30}$$

By repeating this calculation for every time step, the average line can be drawn, see Figure 5.

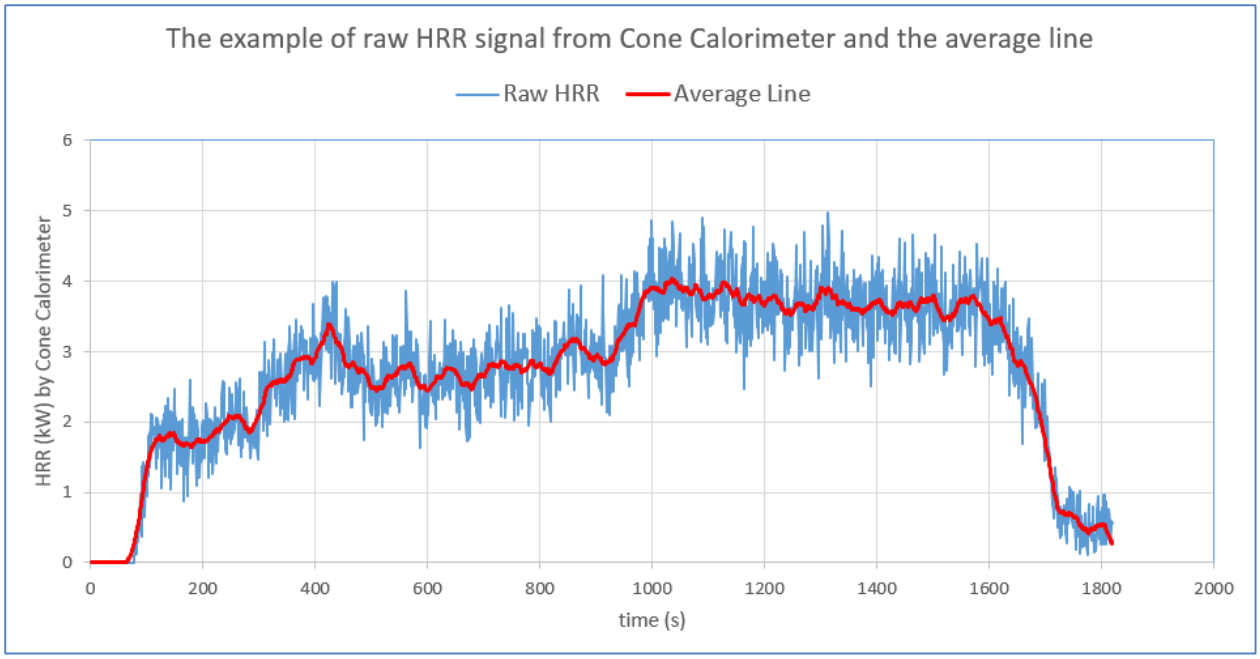

Figure 5 Demonstration of a raw HRR curve and an average line

The next challenging aspect is that what the most appropriate range of average time should be. To figure out this problem, the examples of two ranges which are 10 seconds and 30 seconds will be examined respectively.

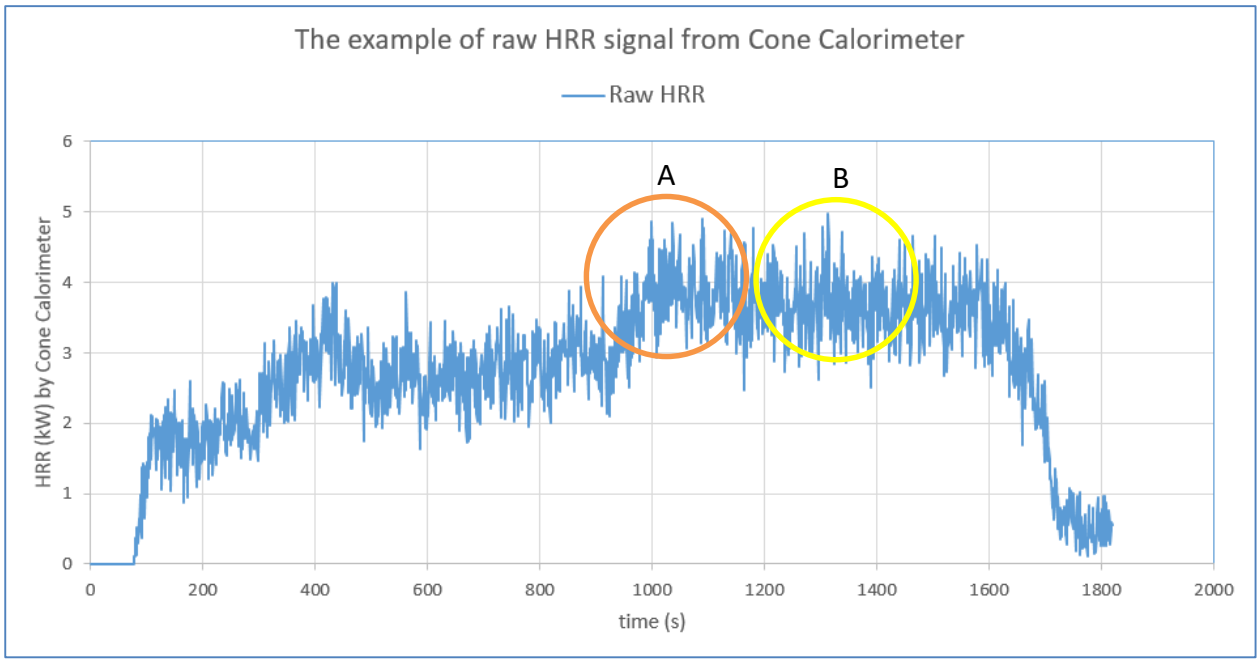

Figure 6 Raw HRR signal from cone calorimeter

Figure 6 shows the ordinary raw HRR signal from the cone calorimeter. It can be observed by basic engineering judgement that the real peak HRR should fall into region A rather than region B.

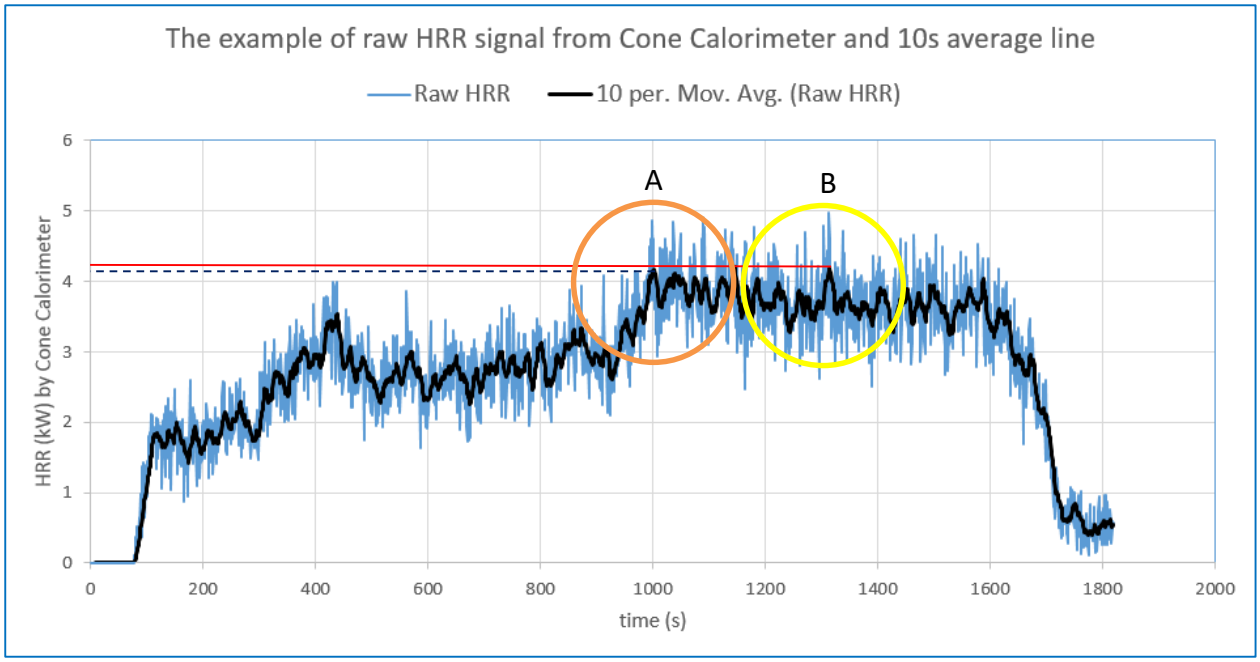

Figure 7 Demonstration of 10 seconds average line

A 10 seconds average line in Figure 7 indicates that the peak HRR falls into region B instead of A. This indication contradicts to the common observation therefore the 10 seconds average line is not good enough to capture the real peak HRR.

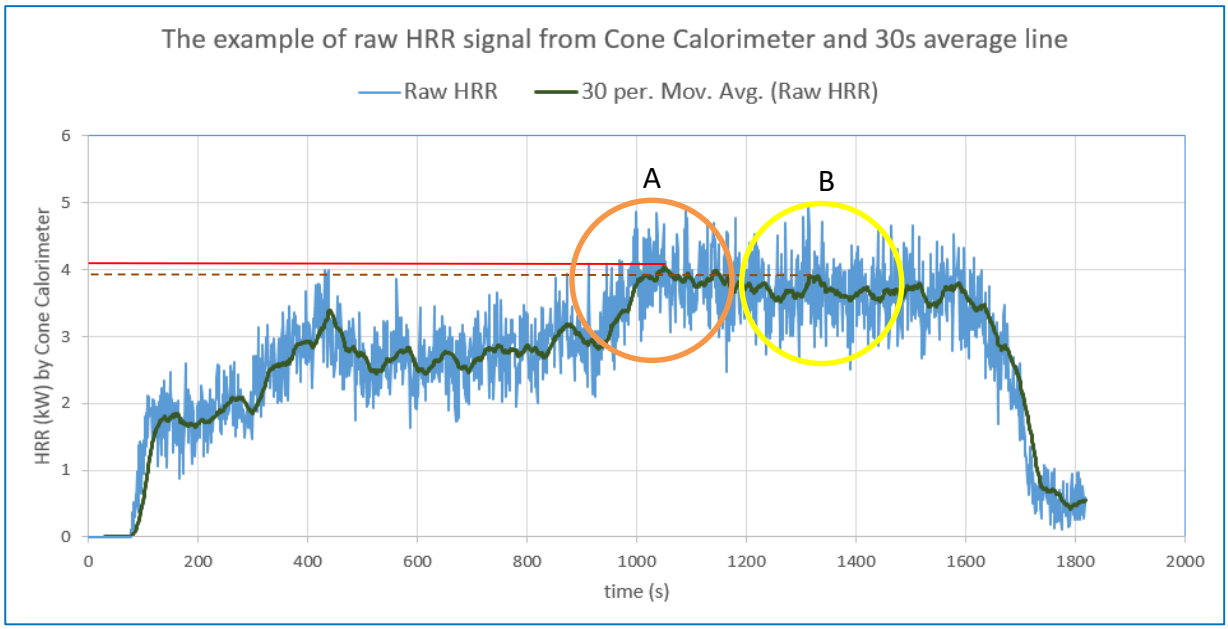

Figure 8 Demonstration of 30 seconds average line

The reasonable peak HRR is obtained by applying a 30 seconds average line as shown in Figure 8. The position of the peak is in region A as expected therefore the 30 seconds range seems to be a good value.

In the FIPEC project, the 30 seconds average line was used in data analyzing process such as peak HRR determination [5]. This confirms that the chosen value of 30 seconds as the average time range is the optimum value and ensures that FIPEC and FIPECMATCH are on the same basis.

4.4 Peak HRR (3) and Time to Peak HRR (4) Capture

After the average line is established, the value of average HRR is investigated time step by time step in the programmatic manner in order to seek the peak HRR. Once the HRR investigation is finished the peak HRR is collected as well as the time to the peak then these two values are recorded in the calculation file. Figure 9 shows the logic of the capture process.

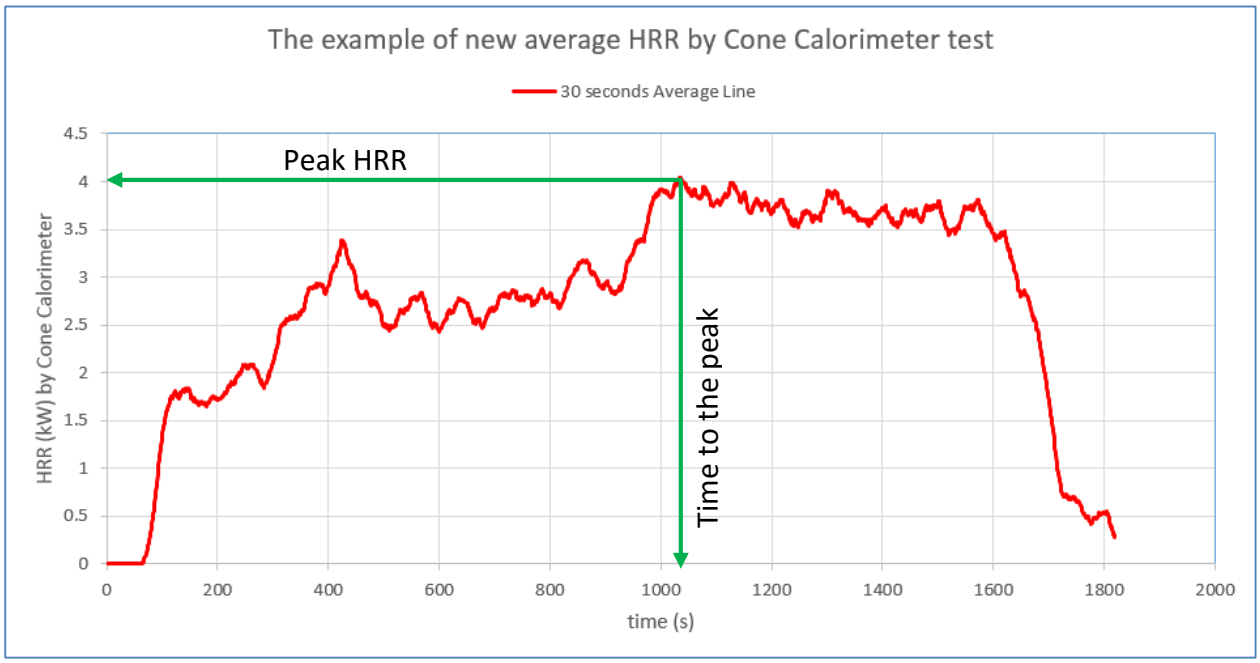

Figure 9 Peak HRR and time to the peak capture logic

It should be noted here that the cable specimens are prepared and tested in such a way that the test procedures according to the ISO5660 are followed. The results of the peak HRR and the time to the peak are considered as the property of those tested cables. The repeatability and the reproducibility should be achieved in very narrow deviation limit.

4.5 The new HRR input and HRR database comparison (5), (6)

As mentioned in the previous section, the repeatability and reproducibility are profound in the cable testing field. During FIPEC experiments, these two characteristics were proved as follows.

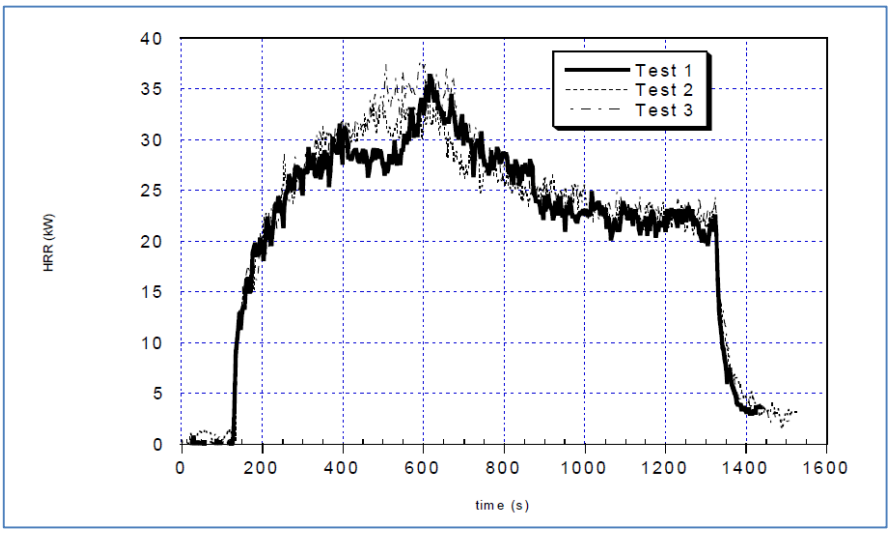

Figure 10 FIPEC's repeatability (excerpted from [4])

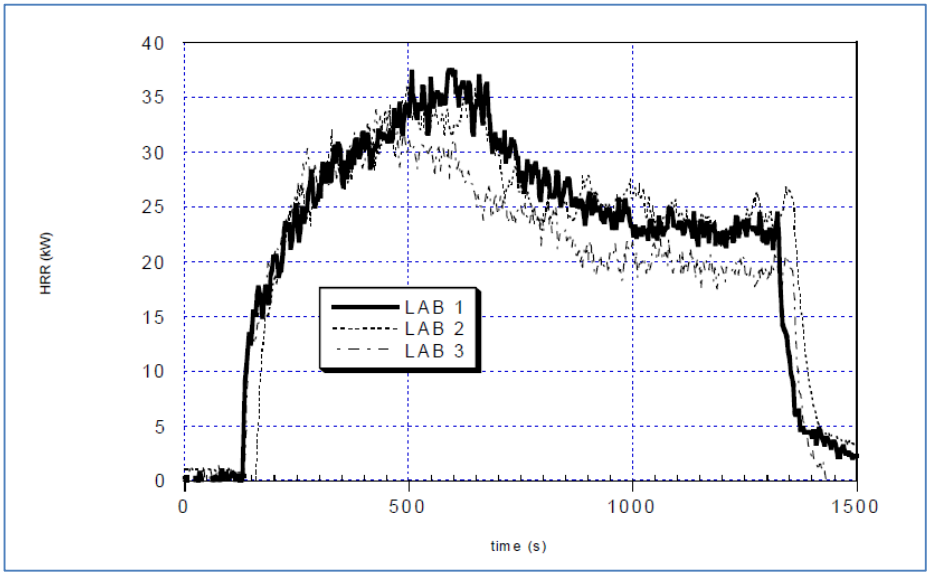

Figure 11 FIPEC's reproducibility (excerpted from [4])

The HRR results shown in Figure 10 and 11 are almost identical between each testing. Only very limited difference can be observed. Nevertheless, for the first filter boundary of FIPECMATCH, it is not necessary to be strict to narrow limitation since the thorough scrutiny will be performed in the second filter process. The first filter bound value for the peak HRR is set to be $\pm$ 30% whereas the bound value for the time to the peak is set to be $\pm$ 120s so as to open the broad entrance for making the short list.

However, it should be emphasised here that the bound values, ± 30% of the peak HRR and ± 120s of the time to the peak, are obtained from the repeatability and reproducibility study of FIPEC project. It is possible to observe from Figure 10 and 11 that the deviation among each test and each laboratory was in these bound values.

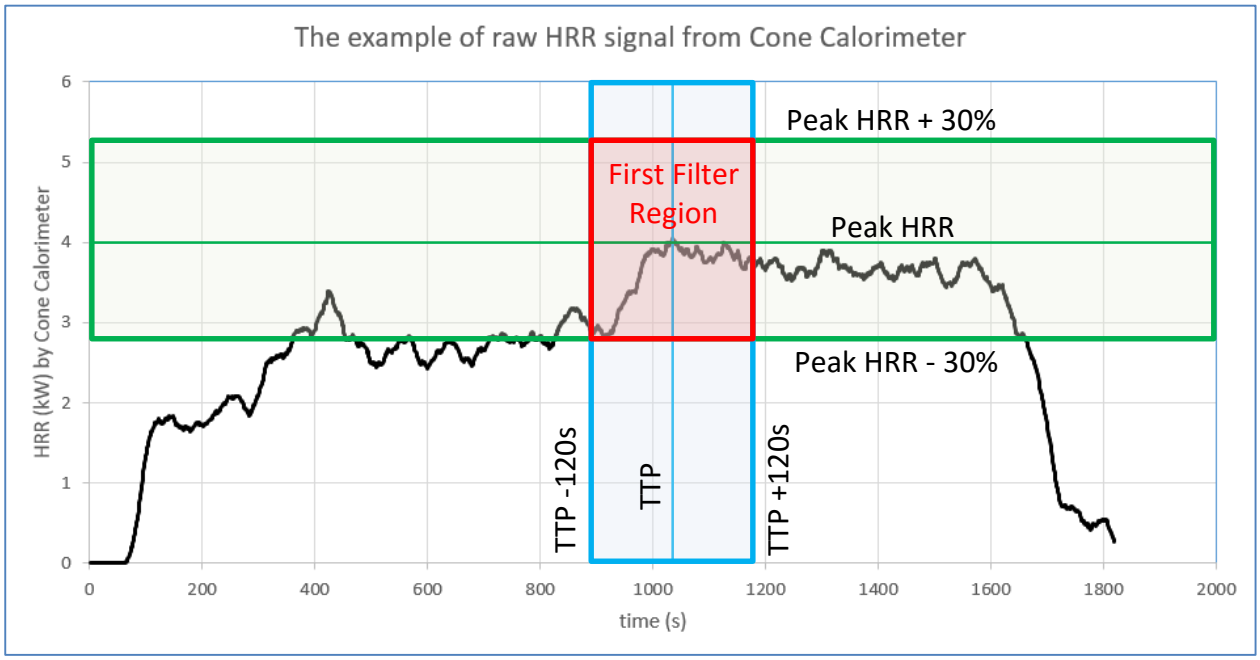

Figure 12 The bound values for first filter of FIPECMATCH

All HRR patterns stored in the database which have the peak HRR point with in the first filter region, see Figure 12, will be pinpointed and allocated in the short list waiting for the second filter process.

4.6 The similarity calculation (7), (8), (9), (10), (11), (12)

The most important process of FIPECMATCH is the similarity evaluation in the work of the second filter module. The first filter screens the potential matched HRR stored in the database as the short list. Its work escalates the whole process speed because the second filter will work on the high potential matched HRR only rather than running over the database as a whole. The task of the second filter is checking the similarity of the HRR pattern between the new input and the database in the short list one by one and throughout the burning interval. Figure 13 shows the main idea of the similarity comparison.

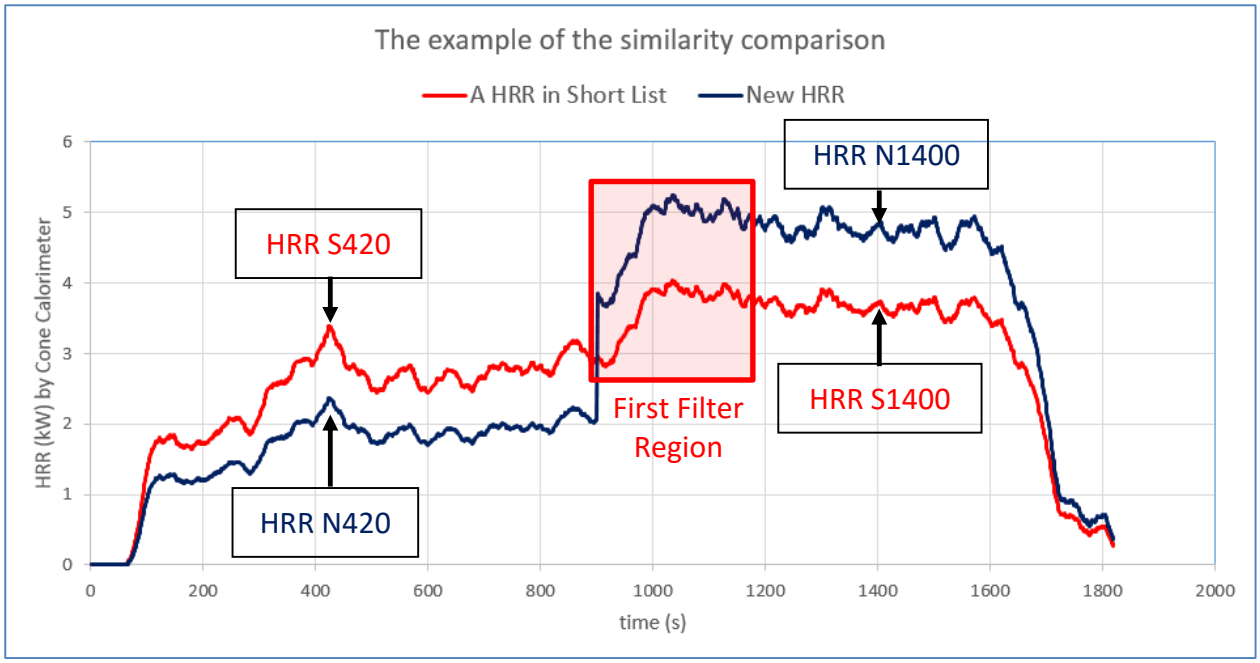

Figure 13 The main idea of similarity comparison

The similarity is the proportion between the pair in comparison. If they are identical, the similarity will be unity or in other words the similarity is 100%. If there are some deviations, the similarity will reduce in proportion to the differences. The following equations are the equations to calculate the instant similarity in two situations.

$$SML = \frac{HRR\ N}{HRR\ S} \times 100\ \% \qquad \text{where HRR S} \geq \text{HRR N}$$

$$SML = \frac{HRR\ S}{HRR\ N} \times 100\ \% \qquad \text{where HRR S} < \text{HRR N}$$

For example,

The instant similarity at t = 420s can be calculated as,

$$SML\ 420 = \frac{HRR\ N420}{HRR\ S420} \times 100.$$

Whereas the instant similarity at t = 1,400s can be calculated as,

$$SML\ 1400 = \frac{HRR\ S1400}{HRR\ N1400} \times 100.$$

By repeating the calculation for every time step, the instant similarity of each time step is obtained and recorded.

It should be noted here that the comparison is divided into three zones. The first zone has zero HRR both new input HRR and reference HRR where the similarity is set to be 100%. The second zone has the values of HRR both new input HRR and reference HRR where the

similarity is calculated as the proportion between the pair in comparison. The third zone has the value of HRR only from one side of the pair in comparison where the value of HRR from the other side is zero or absent. The similarity is set to be zero for the third zone. The total number of time step in comparison (N) is the time step from step zero to the longer time step among the pair in comparison. Figure 15 illustrates this concept.

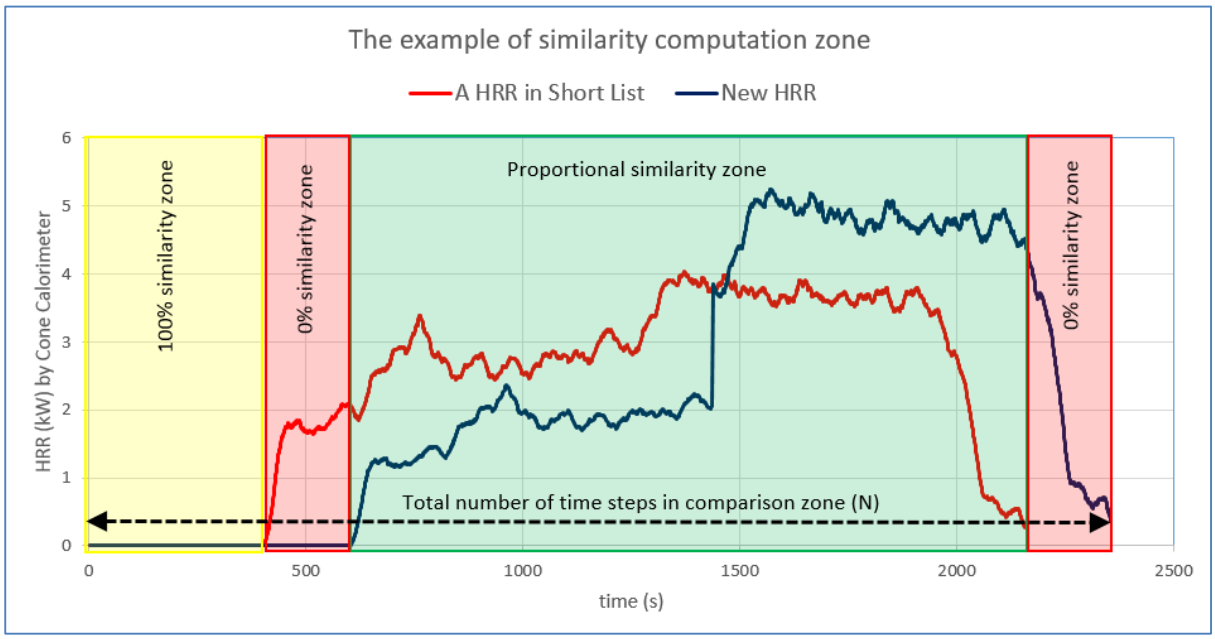

Figure 14 The example of similarity computation zone

After the instant similarity for all time steps in the comparison area is recorded, the average similarity as the representative value of the pair is calculated by the following equation.

$$SML_{AVE} = \frac{\sum_{i=1}^{N} SML_i}{N}$$

Where,

SML_{AVE}	:	The average similarity (%)
SML_i	:	The instant similarity for each time step (%)
i	:	Time step in comparison zone
N	:	Total number of time step in the comparison zone.

By repeating the whole process for all data in the short list, all data will have their average similarity value recorded.

In the last process of the second filter, the average similarity for each data will be sorted and allocated in the descending order. The top order would be the highest similarity, which will be examined whether or not it is more than 70%. If the highest similarity is more than or equal to 70%, the matching is deemed to be satisfactory, on the other hand if the highest similarity is less than 70%, the matching is considered as mismatching.

It should be remarked here that the matching criterion, 0.7 or 70%, is considered as the imperfect factor which is usually found in fire discipline for example the combustion efficiency factor and the flow coefficient [6]. This criterion is based on the nature of each experiment by means of how well each experiment can be repeated and reproduced. The results in section 5 support the chosen value, 0.7, because it yields the correct comparison and selection.

4.7 The corresponding full-scale HRR (13)

The procedures for small-scale cable test and the full-scale test of FIIPEC project were set as the standard testing method and the repeatability together with the reproducibility are highly successful. For this reason, whenever the same result of the small-scale cable is found, the same result of the full-scale should be met explicitly. Figure 15 and 16 describe the concept idea.

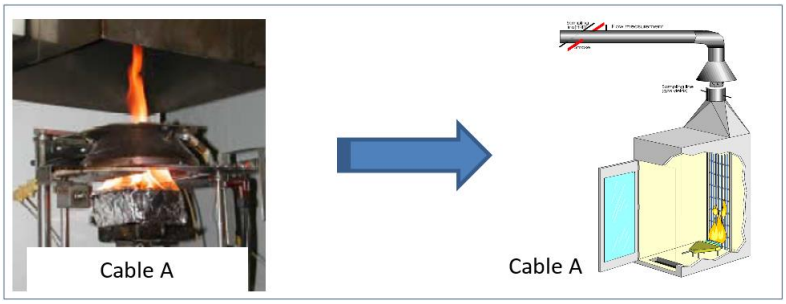

Figure 15 The concept idea of FIPEC project (modified from [4])

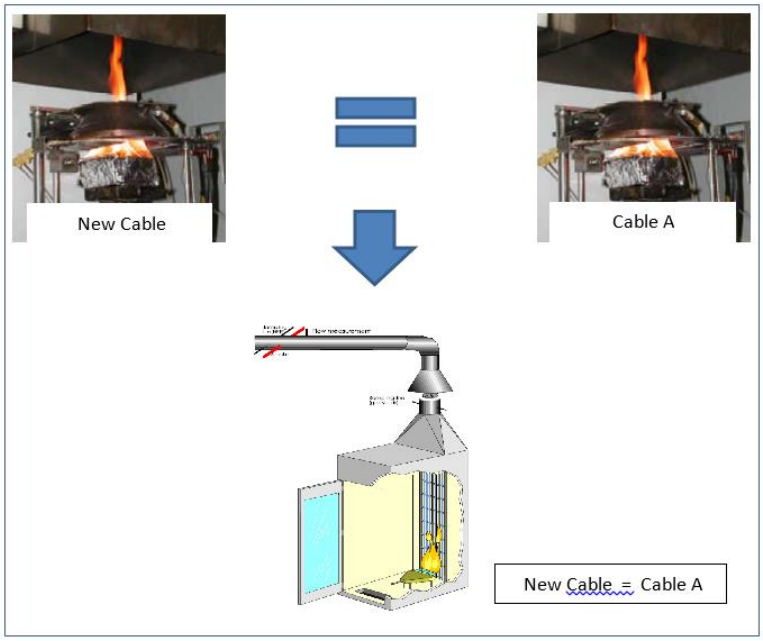

Figure 16 The concept idea of FIPECMATCH (modified from [4])

5. Results

This section will show the performance of FIPECMATCH in terms of verification and validation together with some input varieties. Since this package is considered as one type of computer software, the verification and validation is important to test the reliability. Various HRR inputs will be put in the running process and the outcomes will be presented.

5.1 Accessing FIPECMATCH

FIPECMATCH is a cloud computing programme which is a free application of Google and therefore it bases on Google website server. The URL for accessing this software is as follow.

https://sites.google.com/site/fipecmatch/

The alternative access is QR code which is shown in Figure 17.

Figure 17 FIPECMATCH's QR Code

5.2 Verification

The common definition of verification is “the process of determining that a calculation method implementation accurately represents the developer's conceptual description of the calculation method and the solution to the calculation method” [7] or in simple words “solve equation correct”. This means that FIPECMATCH selects the correct database when it performs a running process both the exact HRR and similar HRR.

To verify this package, several HRR inputs were tested as shown in Table 1, section 5.2.16. The Cable FIPEC-15 with the imposed heat flux 50 kW/m^2 was chosen as an example in order to introduce the verification process in great details.

5.2.1 Matching with the exact HRR

The exact HRR of Cable FIPEC-15 or 100% similarity was put into the programme. The expected result is that FIPECMATCH should give the matching cable code of FIPEC-15 with 100% similarity rather than other FIPEC codes. Figure 18 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 19.

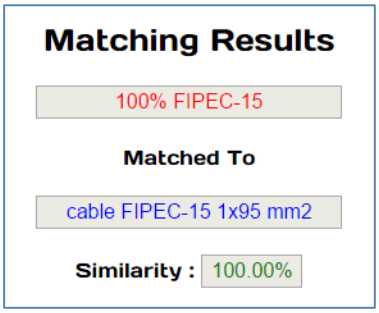

Figure 18 The exact HRR matching result

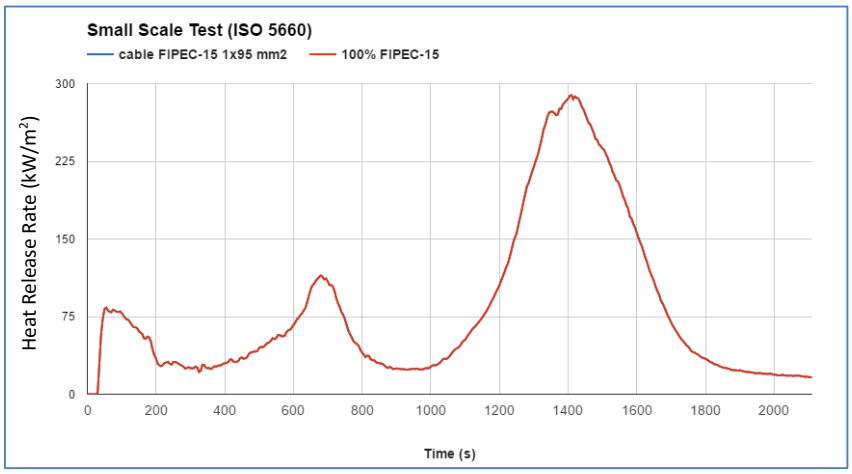

Figure 19 The exact HRR comparison

The outcome turned out as expected. The exact HRR has the similarity of 100% as well as the exact HRR graph was overwritten on the same pattern as Cable FIPEC-15 perfectly.

5.2.2 Matching with the 30% lower HRR

The 30% lower HRR is obtained by multiplying the factor of 0.7 to the Cable FIPEC-15 HRR. The expected result is that FIPECMATCH should give the matching cable code of FIPEC-15 with 70% similarity rather than other FIPEC codes. Figure 20 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 21.

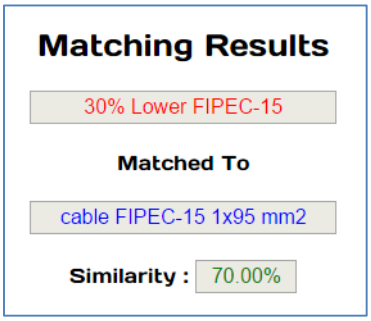

Figure 20 The 30% lower HRR matching result

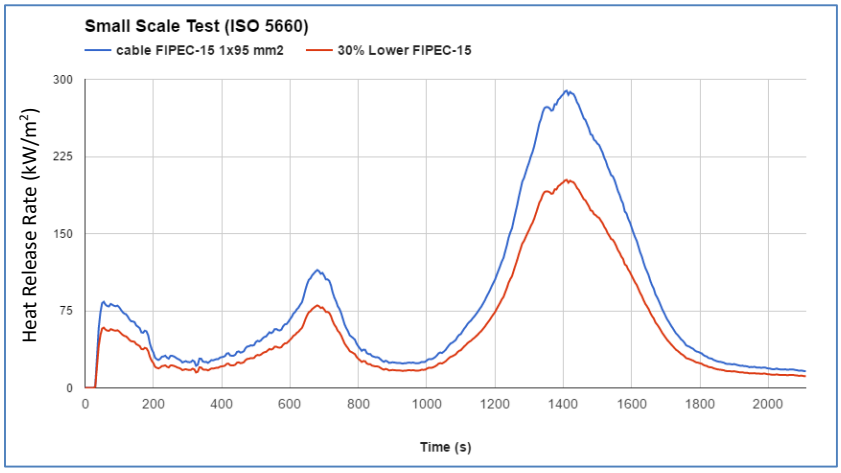

Figure 21 The 30% lower HRR comparison

The outcome turned out as expected. The 30% lower HRR has the similarity of 70% while the HRR comparison graph shows the comprehensive similarity to the Cable FIPEC-15 clearly.

5.2.3 Matching with the 30% higher HRR

The 30% higher HRR is obtained by multiplying the factor of 1.3 to the Cable FIPEC-15 HRR. The expected result is that FIPECMATCH should give the matching cable code of FIPEC-15 with 77% similarity rather than other FIPEC codes. Figure 22 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 23.

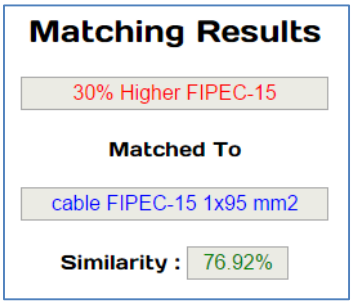

Figure 22 The 30% higher HRR matching result

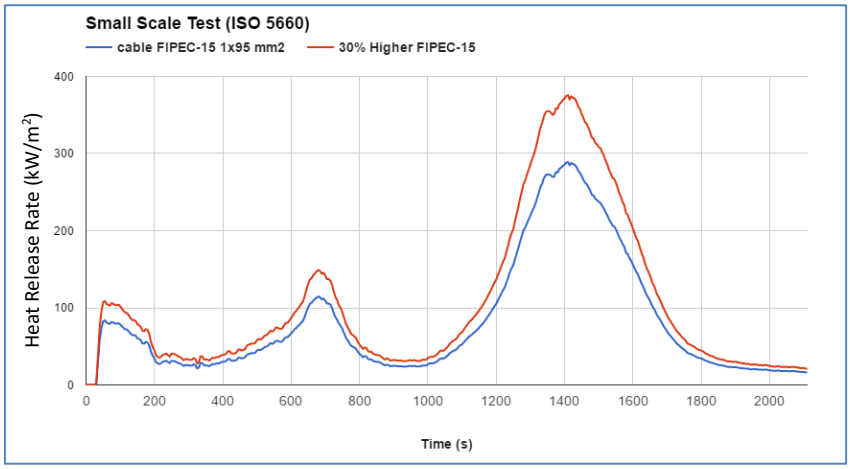

Figure 23 The 30% higher HRR comparison

The outcome turned out as expected. The 30% higher HRR has the similarity of 76.92% while the HRR comparison graph shows the comprehensive similarity to the Cable FIPEC-15 clearly.

5.2.4 Matching with the 60 seconds earlier HRR

The 60 seconds earlier HRR is obtained by translating of the Cable FIPEC-15 HRR to the left. The expected result is that FIPECMATCH should give the similarity lower than 100% and there is possibility to match another cable code which yields higher similarity than the Cable FIPEC-15. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 24 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 25.

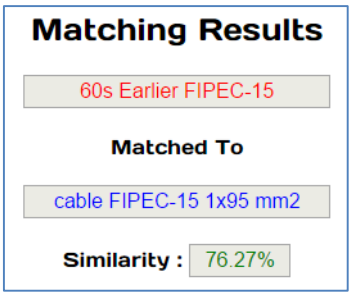

Figure 24 The 60s earlier HRR matching result

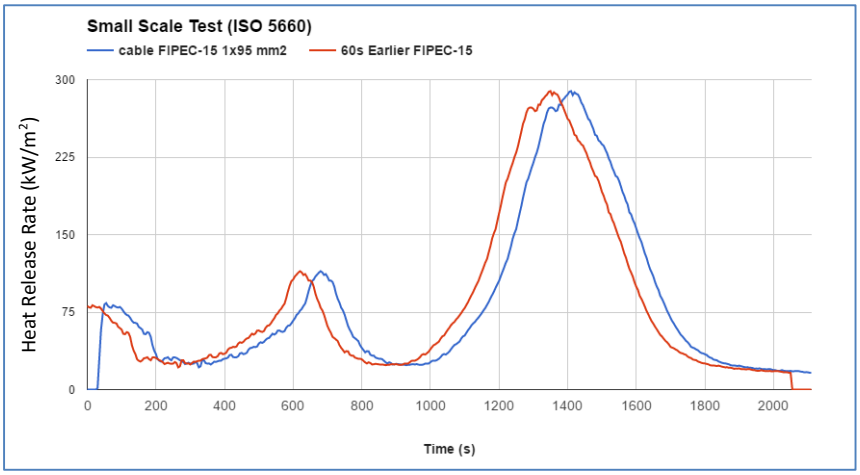

Figure 25 The 60s earlier HRR comparison

The outcome was still matched to FIPEC-15 with 76.3% similarity as expectation and the HRR comparison graph shows the comprehensive similarity to the Cable FIPEC-15 clearly.

It should be noted here that the similarity decreases dramatically for the time translation case. For example, only 60 seconds earlier in this case, the similarity decreased from 100% to 76.3%. This can be expected that if the HRR is speeded up further, the similarity will fall below 70% and the result should turn to be mismatching.

It is wise to check the close-by items in the short list, which is the background running process. There are two items, which are FIPEC-15 and FIPEC-22 in the short list for this case as shown in Figure 26. If the HRR is speeded up further, the similarity of FIPEC-15 will be decreased while the similarity of FIPEC-22 may be increased and higher than FIPEC-15. If this situation is the case, the most similar database will be FIPEC-22 instead of FIPEC-15.

FIPEC Code	Similarity	Pair No
cable FIPEC-15	76.27373162	38
Cable FIPEC-22	55.93497829	59

Figure 26 The close-by items for 60s earlier HRR

5.2.5 Mismatching with the 120 seconds earlier HRR

The 120 seconds earlier HRR is obtained by translating of the Cable FIPEC-15 HRR to the left. The expected result is that FIPECMATCH should give the similarity lower than 76.3%, the previous section, and there is possibility to match another cable code which yields higher similarity than the Cable FIPEC-15. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 27 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 28.

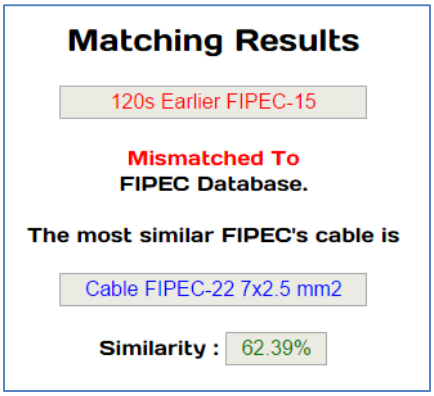

Figure 27 The 120s earlier HRR matching result

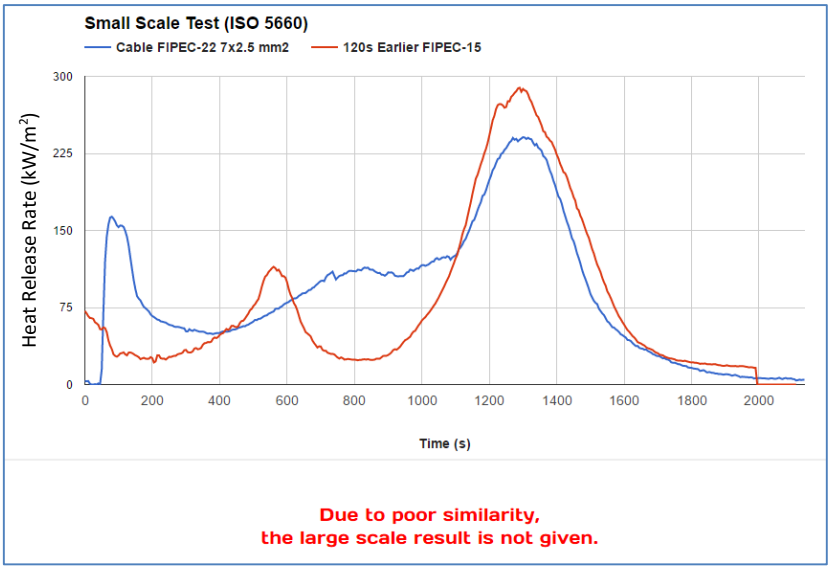

Figure 28 The 120s earlier HRR to FIPEC-22 comparison

The outcome was matched to FIPEC-22 with 62.4% similarity instead of FIPEC-15 as expectation because FIPEC-22 has higher similarity than FIPEC-15. There are two items in the short list, which are FIPEC-22 and FIPEC-15 with the similarity only 60.2% as shown in Figure 29. The HRR comparison graph of FIPEC-15 is drawn up in Figure 30.

FIPEC Code	Similarity	Pair No
Cable FIPEC-22	62.38717128	59
cable FIPEC-15	60.20844086	38

Figure 29 The close-by items for 120s earlier HRR

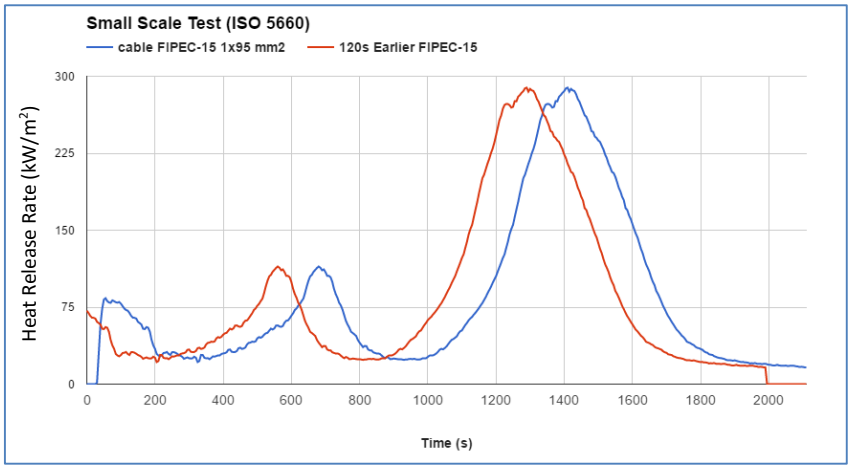

Figure 30 The 120s earlier HRR to FIPEC-15 comparison

According to the definition of the similarity in the previous section, the similarity is the proportion between the pair in comparison time step by time step, it can be seen that FIPEC-22 in Figure 28 is more similar to the input than FIPEC-15 in Figure 30 however sometimes it is quite hard to judge by the eyesight because of very slight difference, 62.4% to 60.2%.

Although the FIPEC-22 is the most similar database, it is considered as poor similarity because the similarity is only 62.4% which is lower than the bound value, 70%. This case is mismatching and the full-scale testing result will not be given.

5.2.6 Matching with the 60 seconds later HRR

The 60 seconds later HRR is obtained by translating of the Cable FIPEC-15 HRR to the right. The expected result is that FIPECMATCH should give the similarity lower than 100% and there is possibility to match another cable code which yields higher similarity than the Cable FIPEC-15. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 31 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 32.

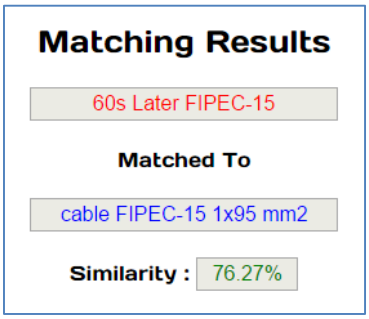

Figure 31 The 60s later HRR matching result

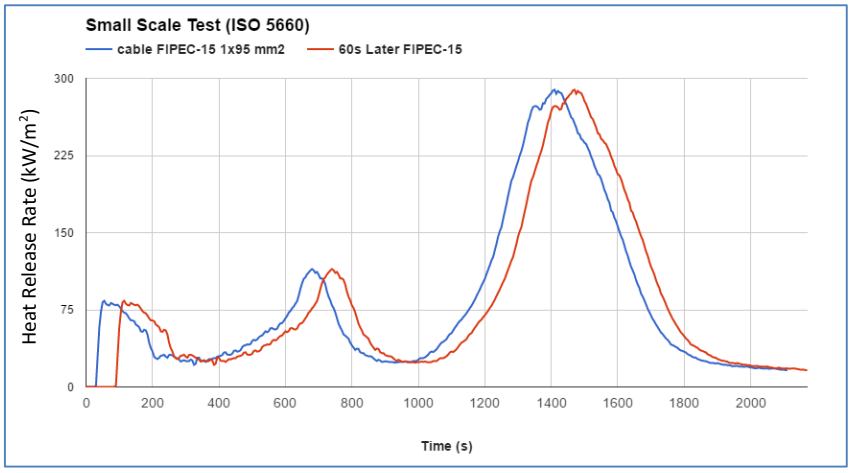

Figure 32 The 60s later HRR comparison

The outcome was still matched to FIPEC-15 with 76.3% similarity as expectation and the HRR comparison graph shows the comprehensive similarity to the Cable FIPEC-15 clearly.

It should be noted here that the similarity decreases dramatically for the time translation case. For example, only 60 seconds later in this case, the similarity decreased from 100% to 76.3%. This can be expected that if the HRR is slowed down further, the similarity will fall below 70% and the result should turn to be mismatching.

It is wise to check the close-by items in the short list, which is the background running process. There is only FIPEC-15 in the short list for this case as shown in Figure 33. If the HRR is slowed down further, the similarity of FIPEC-15 will be decreased lower than 70%. For this situation, the matching result should be mismatching because of poor similarity.

FIPEC Code	Similarity	Pair No
cable FIPEC-15	76.27373162	38

Figure 33 Close-by item for 60s later HRR

5.2.7 Mismatching with the 120 seconds later HRR

The 120 seconds later HRR is obtained by translating of the Cable FIPEC-15 HRR to the right. The expected result is that FIPECMATCH should give the similarity lower than 76.3%, the previous section and there is no possibility to match another cable code since there is only the Cable FIPEC-15 in the short list for this case. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 34 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 35.

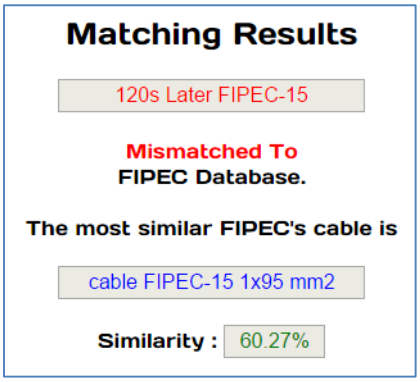

Figure 34 The 120s later HRR matching result

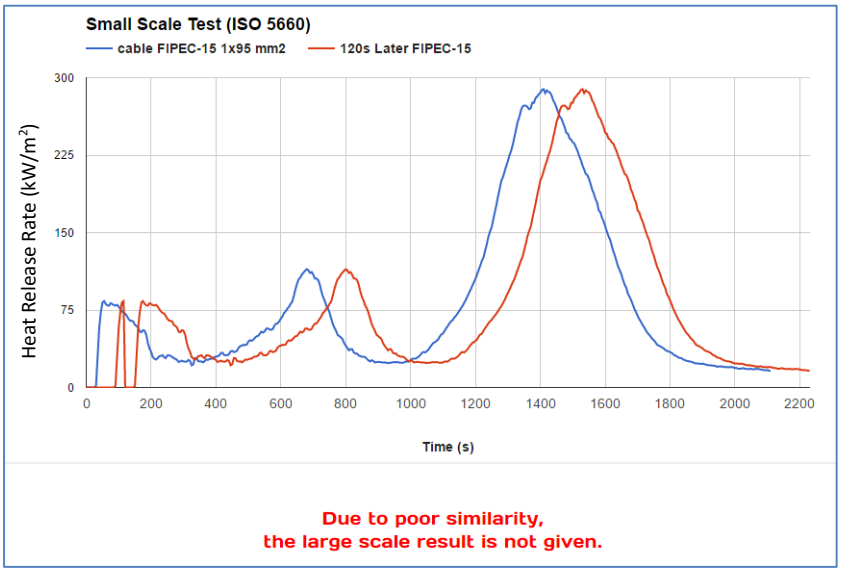

Figure 35 The 120s later HRR comparison

The outcome was mismatching however the FIPEC-15 was still the most similar database as expectation. Since the similarity is only 60.3% lower than bound value, 70%, this case is considered as poor similarity and the full-scale testing result will not be given.

5.2.8 Mismatching with the 50% lower HRR

The 50% lower HRR is obtained by multiplying the factor of 0.5 to the Cable FIPEC-15 HRR. The expected result is that the result should not be matched with FIPEC-15 because the input value is out of the bound value. There is possibility to match any cable code, which yields the highest similarity. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 36 shows the matching result copied from the webpage. In case of mismatching, this HRR is considered as a new cable therefore the getting more information module will be shown up in order to prompt the users if they prefer to share their cable's information with FIPECMATCH.

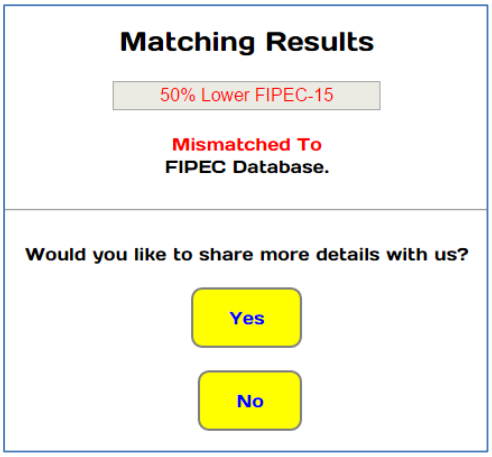

Figure 36 The 50% lower HRR matching result

The outcome turned out as expectation. The case was mismatching without any most similar result and the getting more information module was invoked.

It should be noted here that the getting more information module will be called up whenever the mismatching occurs regardless whether or not there will be the most similar database.

5.2.9 Mismatching with the 50% higher HRR

The 50% higher HRR is obtained by multiplying the factor of 1.5 to the Cable FIPEC-15 HRR. The expected result is that the result should not be matched with FIPEC-15 because the input value is out of the bound value. There is possibility to match any cable code, which yields the highest similarity. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 37 shows the matching result copied from the webpage. In case of mismatching, this HRR is considered as a new found cable therefore the getting more information module will be shown up in order to prompt the users if they prefer to share their cable's information with FIPECMATCH.

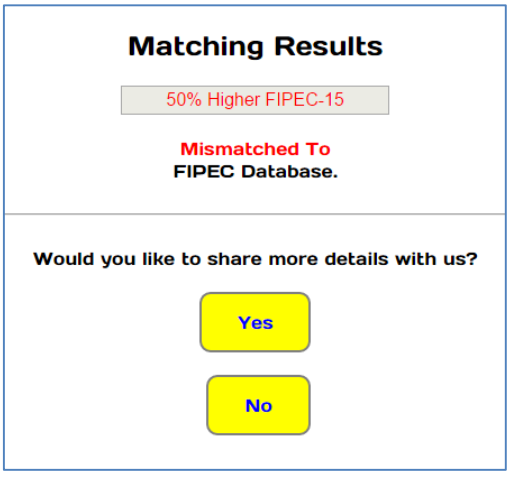

Figure 37 The 50% higher HRR matching result

The outcome turned out as expected. The case was mismatching without any most similar result and the getting more information module was invoked.

5.2.10 Mismatching with the 240 seconds earlier HRR

The 240 seconds earlier HRR is obtained by translating of the Cable FIPEC-15 HRR to the left. The expected result is that the result should not be matched with FIPEC-15 because the input value is out of the bound value. There is possibility to match another cable code, which yields the highest similarity. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 38 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and the most similar HRR is presented in Figure 39. In case of mismatching, this HRR is considered as new cable therefore the getting more information module will be shown up in order to prompt the users if they prefer to share their cable's information with FIPECMATCH.

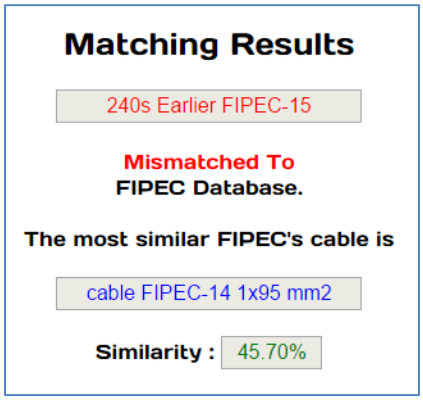

Figure 38 The 240s earlier HRR matching result

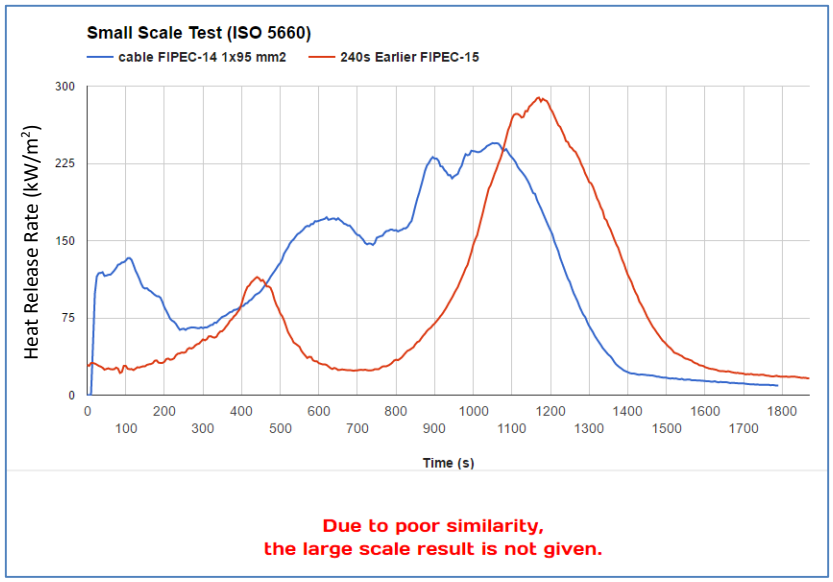

Figure 39 The 240s earlier HRR to FIPEC-14 comparison

The outcome turned out as expected. Although FIPEC-14 is the most similar database, the similarity is poor. The case was mismatching and the getting more information module was invoked as well as the full-scale testing result was not given.

5.2.11 Mismatching with the 240 seconds later HRR

The 240 seconds later HRR is obtained by translating of the Cable FIPEC-15 HRR to the right. The expected result is that the result should not be matched with FIPEC-15 because the input value is out of the bound value. There is possibility to match another cable code, which yields the highest similarity. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 40 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and the most similar HRR is presented in Figure 41. In case of mismatching, this HRR is considered as new found cable therefore the getting more information module will be shown up in order to prompt the users if they prefer to share their cable's information with FIPECMATCH.

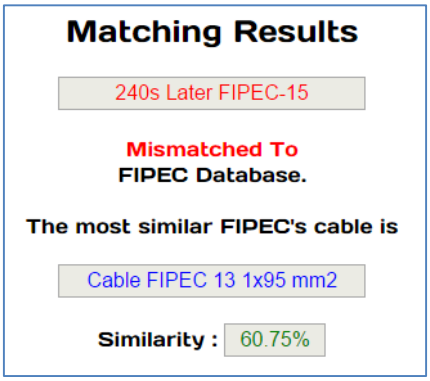

Figure 40 The 240s later HRR matching result

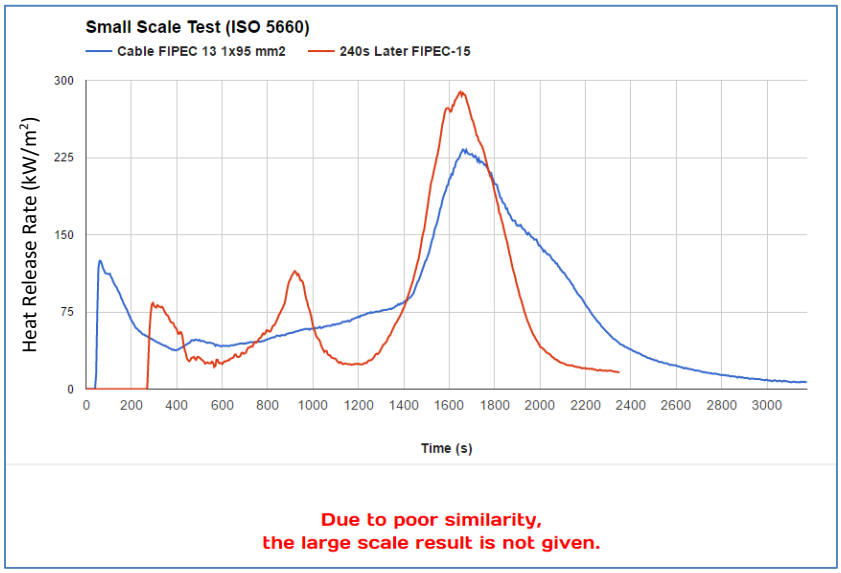

Figure 41 The 240s later HRR to FIPEC-13 comparison

The outcome turned out as expected. Although FIPEC-13 is the most similar database, the similarity is poor. The case was mismatching and the getting more information module was invoked as well as the full-scale testing result was not given.

5.2.12 Matching with the 20% lower and 30 seconds earlier HRR

The 20% lower and 30 seconds earlier HRR is obtained by multiplying the factor of 0.8 to the Cable FIPEC-15 HRR and translation to the left. The expected result is that there is possibility to match any cable code, which yields the highest similarity. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 42 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 43.

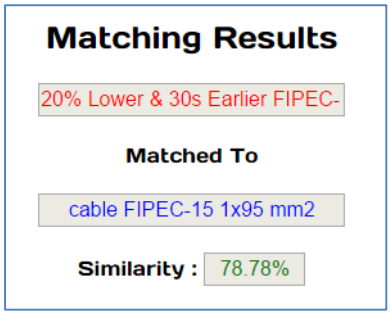

Figure 42 The 20% lower and 30s earlier HRR matching result

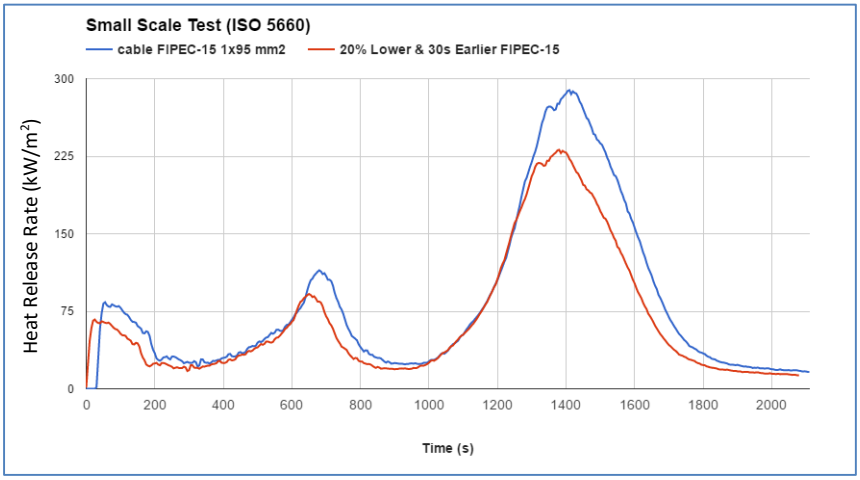

Figure 43 The 20% lower and 30s earlier HRR to FIPEC-15 comparison

The outcome turned out as expected. The 20% lower and 30s earlier HRR was matched to FIPEC-15 with the similarity of 78.8%. The HRR comparison graph in Figure 43 shows the comprehensive similarity to the Cable FIPEC-15 clearly.

5.2.13 Matching with the 20% higher and 30 seconds earlier HRR

The 20% higher and 30 seconds earlier HRR is obtained by multiplying the factor of 1.2 to the Cable FIPEC-15 HRR and translation to the left. The expected result is that there is possibility to match any cable code, which yields the highest similarity. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 44 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 45.

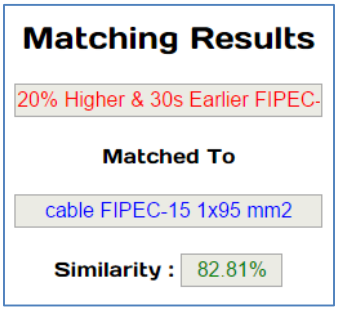

Figure 44 The 20% higher and 30s earlier HRR matching result

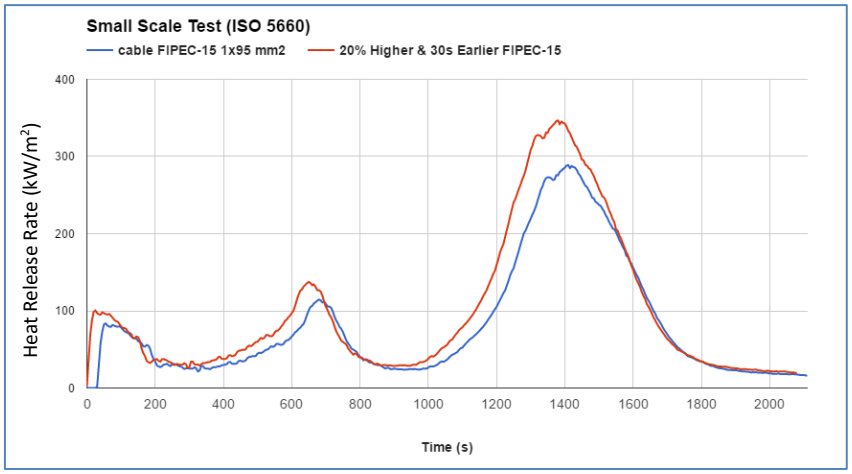

Figure 45 The 20% higher and 30s earlier HRR to FIPEC-15 comparison

The outcome turned out as expected. The 20% higher and 30s earlier HRR was matched to FIPEC-15 with the similarity of 82.8%. The HRR comparison graph in Figure 45 shows the comprehensive similarity to the Cable FIPEC-15 clearly.

5.2.14 Matching with the 20% lower and 30 seconds later HRR

The 20% lower and 30 seconds later HRR is obtained by multiplying the factor of 0.8 to the Cable FIPEC-15 HRR and translation to the right. The expected result is that there is possibility to match any cable code, which yields the highest similarity. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 46 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 47.

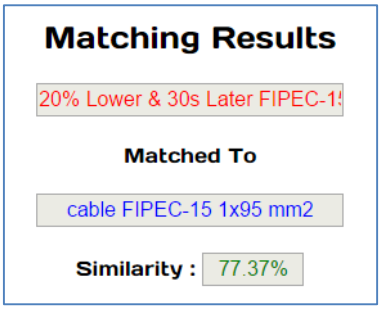

Figure 46 The 20% lower and 30s later HRR matching result

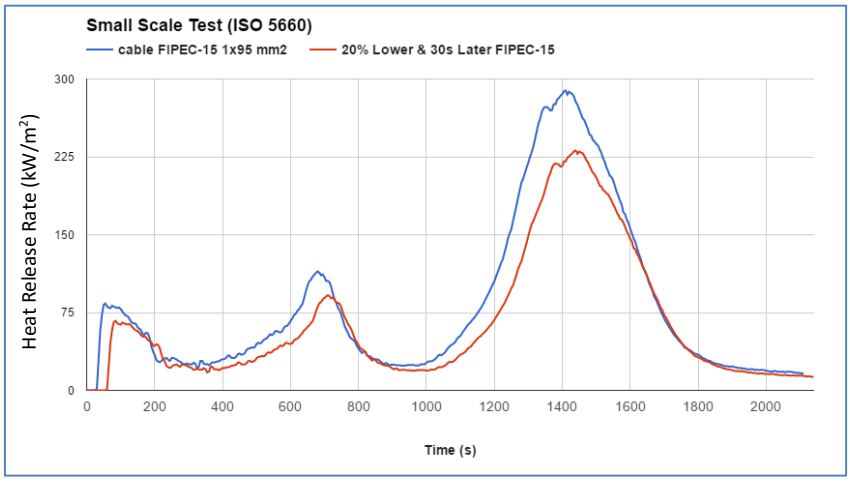

Figure 47 The 20% lower and 30s later HRR to FIPEC-15 comparison

The outcome turned out as expected. The 20% lower and 30s later HRR was matched to FIPEC-15 with the similarity of 77.4%. The HRR comparison graph in Figure 47 shows the comprehensive similarity to the Cable FIPEC-15 clearly.

5.2.15 Matching with the 20% higher and 30 seconds later HRR

The 20% higher and 30 seconds later HRR is obtained by multiplying the factor of 1.2 to the Cable FIPEC-15 HRR and translation to the right. The expected result is that there is possibility to match any cable code, which yields the highest similarity. If the similarity is lower than 70%, the matching result will display as mismatching. Figure 48 shows the matching result copied from the webpage whereas the comparison HRR graph between the input and matched HRR is presented in Figure 49.

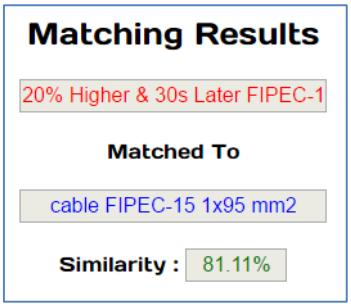

Figure 48 The 20% higher and 30s later HRR matching result

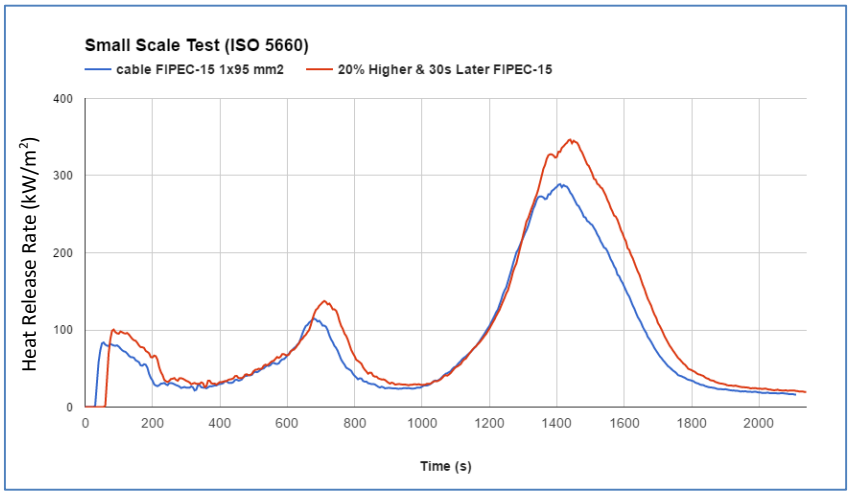

Figure 49 The 20% higher and 30s later HRR to FIPEC-15 comparison

The outcome turned out as expected. The 20% higher and 30s later HRR was matched to FIPEC-15 with the similarity of 81.1%. The HRR comparison graph in Figure 49 shows the comprehensive similarity to the Cable FIPEC-15 clearly.

5.2.16 Verification summary

The following verification cases were tested and the testing results were summarized in table 1.

Table 1 FIPECMATCH verification summary

Input ID	Modification	Expected Result	Result	Verification
1.FIPEC-03	- Exact HRR	- Matched to FIPEC-03 - Similarity 100.0%	- Matched to FIPEC-03 - Similarity 100.0%	- Correct
2.FIPEC-04	- 10% lower	- Matched to FIPEC-04 - Similarity 90.0%	- Matched to FIPEC-04 - Similarity 90.0%	- Correct
3.FIPEC-05	- 10% higher	- Matched to FIPEC-05 - Similarity 90.9%	- Matched to FIPEC-05 - Similarity 90.9%	- Correct
4.FIPEC-06	- 20% lower	- Matched to FIPEC-06 - Similarity 80.0%	- Matched to FIPEC-06 - Similarity 80.0%	- Correct
5.FIPEC-07	- 20% higher	- Matched to FIPEC-07 - Similarity 83.3%	- Matched to FIPEC-07 - Similarity 83.3%	- Correct
6.FIPEC-08	- 30% lower	- Matched to FIPEC-08 - Similarity 70.0%	- Matched to FIPEC-08 - Similarity 70.0%	- Correct

Table 1 FIPECMATCH verification summary (Continue)

Input ID	Modification	Expected Result	Result	Verification
7.FIPEC-09	- 30% higher	- Matched to FIPEC-09 - Similarity 76.9%	- Matched to FIPEC-09 - Similarity 76.9%	- Correct
8.FIPEC-12	- 50% lower	- Mismatched to FIPEC-12 - Possible to match another highest similarity	- Mismatching without the most similarity	- Correct
9.FIPEC-13	- 50% higher	- Mismatched to FIPEC-12 - Possible to match another highest similarity	- Mismatching without the most similarity	- Correct
10.FIPEC-14	- 60s earlier	- Matched to FIPEC-14 - Similarity < 100.0%	- Matched to FIPEC-14 - Similarity 79.6%	- Correct
11.FIPEC-14	- 120s earlier	- Matched to FIPEC-14, Similarity < 79.6% OR - Possible to match another highest similarity	- Most similar to FIPEC-12, similarity = 66.6%	- Correct
12.FIPEC-16	- 60s later	- Matched to FIPEC-16 - Similarity < 100.0%	- Matched to FIPEC-16 - Similarity 87.6%	- Correct
13.FIPEC-16	- 120s later	- Matched to FIPEC-16, Similarity < 87.6% OR - Possible to match another highest similarity	- Matched to FIPEC-16 - Similarity 77.7%	- Correct
14.FIPEC-17	- 20% lower - 30s earlier	- Possible to match another highest similarity	- Matched to FIPEC-38 - Similarity 72.4%	- Correct
15.FIPEC-17	- 20% lower - 60s earlier	- Possible to match another highest similarity	- Matched to FIPEC-38 - Similarity 72.1%	- Correct
16.FIPEC-17	- 20% lower - 120s earlier	- Possible to match another highest similarity	- Most similar to FIPEC-38, similarity = 67.0%	- Correct
17.FIPEC-18	- 20% lower - 30s later	- Possible to match another highest similarity	- Most similar to FIPEC-18, similarity = 54.3%	- Correct
18.FIPEC-18	- 20% lower - 60s later	- Possible to match another highest similarity	- Most similar to FIPEC-18, similarity = 36.7%	- Correct
19.FIPEC-18	- 20% lower - 120s later	- Possible to match another highest similarity	- Most similar to FIPEC-18, similarity = 21.2%	- Correct
20.FIPEC-19	- 20% higher - 30s earlier	- Possible to match another highest similarity	- Matched to FIPEC-19 - Similarity 82.3%	- Correct
21.FIPEC-19	- 20% higher - 60s earlier	- Possible to match another highest similarity	- Matched to FIPEC-19 - Similarity 80.6%	- Correct
22.FIPEC-19	- 20% higher - 120s earlier	- Possible to match another highest similarity	- Matched to FIPEC-19 - Similarity 73.0%	- Correct
23.FIPEC-20	- 20% higher - 30s later	- Possible to match another highest similarity	- Matched to FIPEC-20 - Similarity 80.9%	- Correct
24.FIPEC-20	- 20% higher - 60s later	- Possible to match another highest similarity	- Matched to FIPEC-20 - Similarity 78.9%	- Correct
25.FIPEC-20	- 20% higher - 120s later	- Possible to match another highest similarity	- Matched to FIPEC-20 - Similarity 75.4%	- Correct

5.3 Validation to other material HRRs (ISO5660)

The common definition of validation is “process of determining the degree to which a calculation method is an accurate representation of the real world from the perspective of the intended uses of the calculation method” [7] or in simple words “solve correct equation”. According to the limitation stated in section 3.4, the definition of validation for FIPECMATCH is interpreted as this software should yield matched result only for cable HRR input. If users put another material ISO 5660 HRR, the result should be mismatching.

To validate this package, some other material HRR inputs were downloaded from SP Technical Research Institute of Sweden’s server [8] and were tested as follows.

5.3.1 FR particle board HRR (ISO5660, Flux 75 kW/m^2)

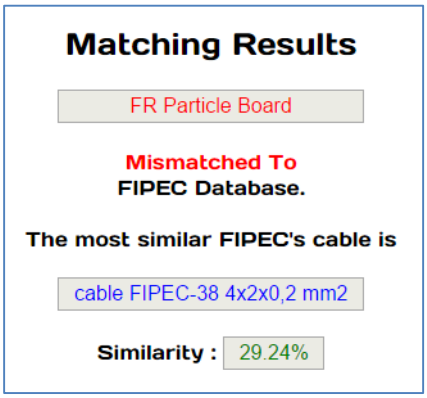

Figure 50 FR particle board matching result

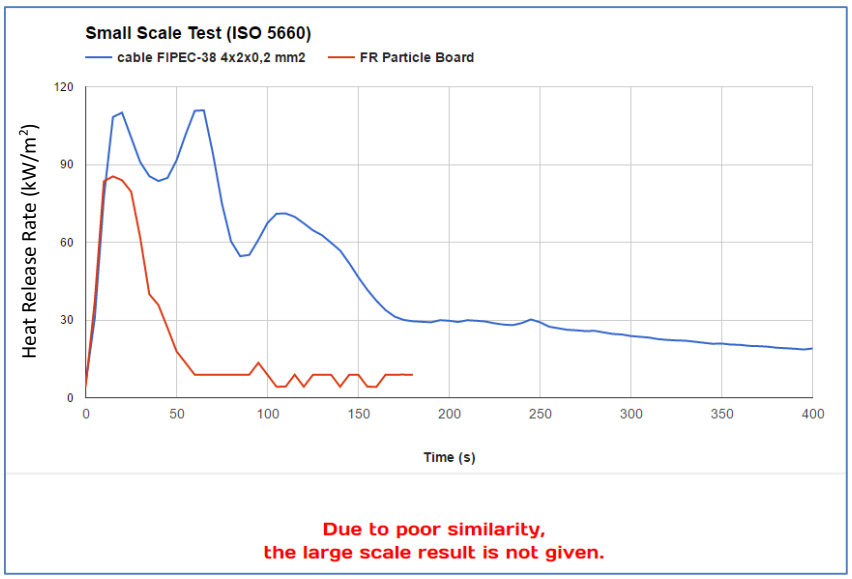

Figure 51 FR particle board to FIPEC-38 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-38 is the most similar pattern, the similarity is poor with only 29.2% as shown in Figure 50. The HRR comparison graph in Figure 51 emphasizes the mismatching.

5.3.2 PUR rigid HRR (ISO5660, Flux 50 kW/m^2)

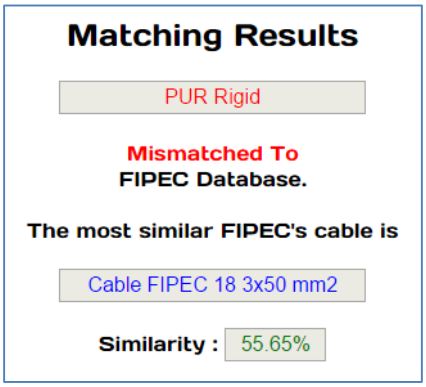

Figure 52 PUR rigid HRR matching result

Figure 53 PUR rigid to FIPEC-18 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-18 is the most similar pattern, the similarity is poor with only 55.7% as shown in Figure 52. The HRR comparison graph in Figure 53 emphasizes the mismatching.

5.3.3 Painted paper plaster board HRR (ISO5660, Flux 50 kW/m^2)

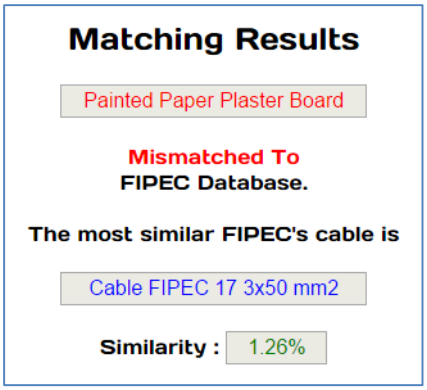

Figure 54 Painted paper plaster board HRR matching result

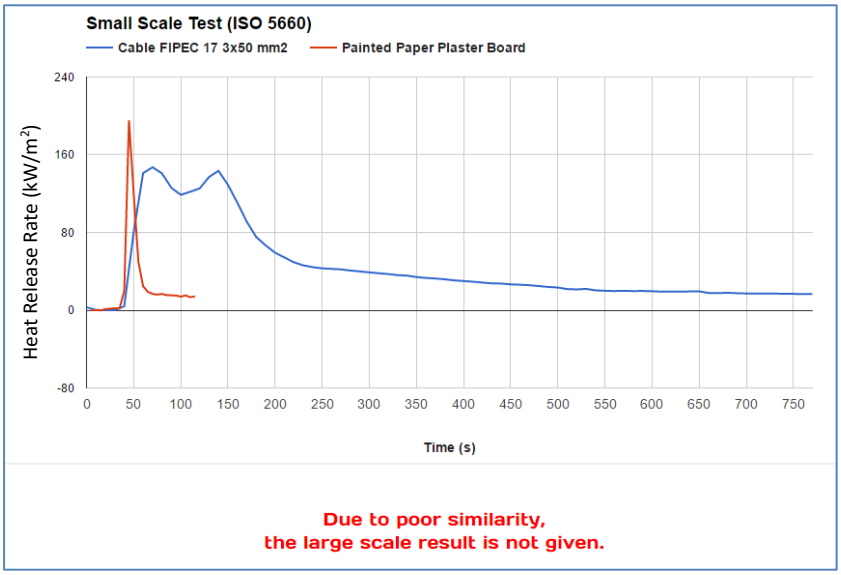

Figure 55 Painted paper plaster board to FIPEC-17 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-17 is the most similar pattern, the similarity is poor with only 1.26% as shown in Figure 54. The HRR comparison graph in Figure 55 emphasizes the mismatching.

5.3.4 Plywood HRR (ISO5660, Flux 50 kW/m^2)

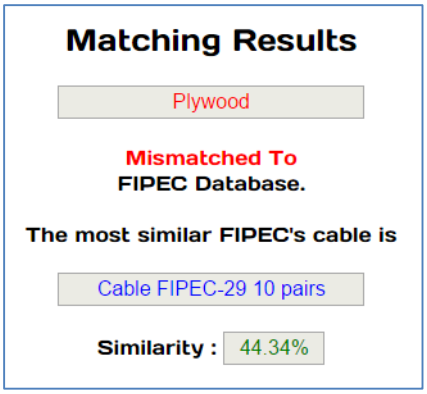

Figure 56 Plywood HRR matching result

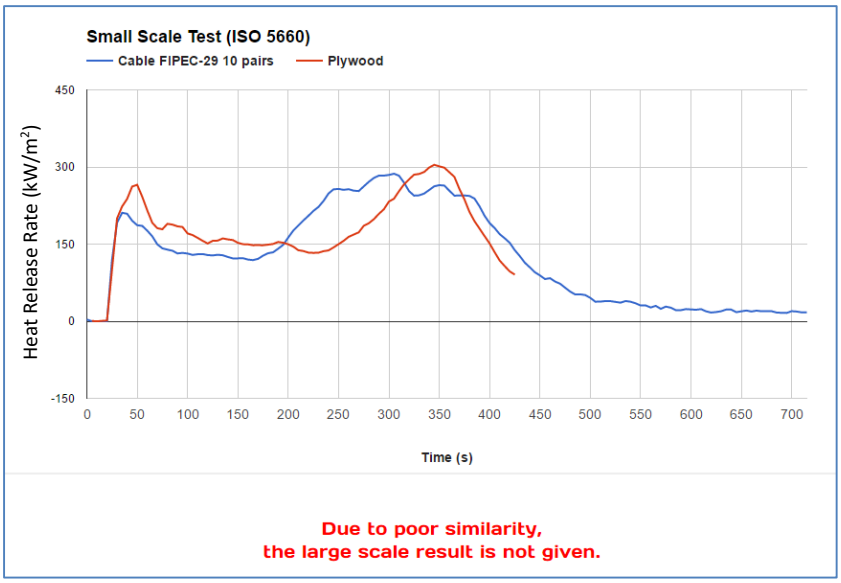

Figure 57 Plywood to FIPEC-29 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-29 is the most similar pattern, the similarity is poor with only 44.34% as shown in Figure 56. The HRR comparison graph in Figure 57 emphasizes the mismatching.

5.3.5 Textile wall covering HRR (ISO5660, Flux 50 kW/m^2)

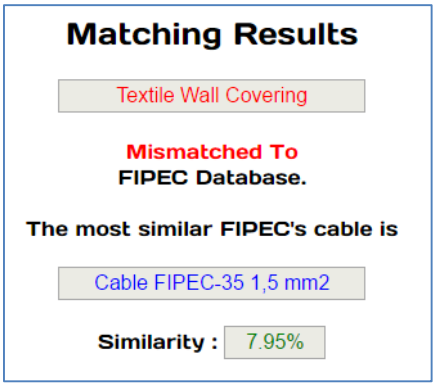

Figure 58 Textile wall covering matching result

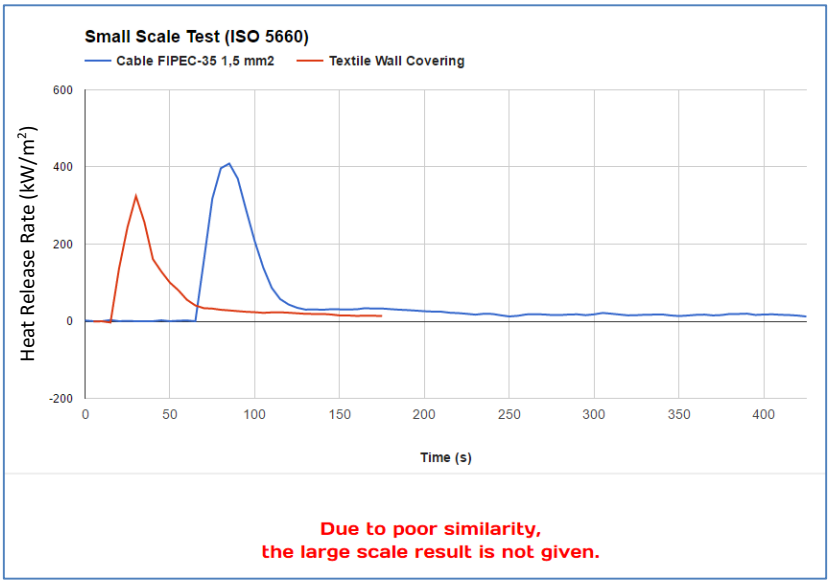

Figure 59 Textile wall covering to FIPEC-35 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-35 is the most similar pattern, the similarity is poor with only 7.95% as shown in Figure 58. The HRR comparison graph in Figure 59 emphasizes the mismatching.

5.3.6 Validation summary

The ISO5660 HRR of various materials from SP's server were downloaded in order to test FIPECMATCH's validation. The results are summarized in Table 2.

Table 2 FIPECMATCH validation summary

SP's ID	Material 1	Material 2	Flux (kw/m^2)	Result	Most similarity
73	FR particle board	-	75	Mismatching	None
82	PUR rigid	Plastic faced steel sheet	35	Mismatching	None
100	Plywood	-	50	Mismatching	FIPEC-29, 45%
110	Painted paper	plasterboard	50	Mismatching	FIPEC-21, 23%
114	Textile wall covering	paper plasterboard	35	Mismatching	FIPEC-33, 18%
122	PVC wall carpet	paper plasterboard	35	Mismatching	FIPEC-21, 45%
132	Plastic faced steel sheet	Mineral wool	50	Mismatching	None
136	Melamine face	Calcium silicate board	75	Mismatching	FIPEC-38, 55%
140	FR EPS	Calcium silicate board	35	Mismatching	None
146	FR particle board	-	50	Mismatching	FIPEC-34, 18%
158	FR particle board	-	50	Mismatching	None
234	PVC wall carpet	Plasterboard	50	Mismatching	FIPEC-34, 38%
235	Wall paper	Particle board	50	Mismatching	None
236	Intumescent paint	Particle board	50	Mismatching	None
237	Textile wall paper	Calcium silicate board	50	Mismatching	FIPEC-33, 9%
238	FR chip board	-	50	Mismatching	None
239	Plywood (birch)	-	50	Mismatching	FIPEC-29, 19%
240	FR polycarbonate	-	50	Mismatching	FIPEC-39, 20%
241	MDF board	-	50	Mismatching	FIPEC-40, 53%
242	Spruce	-	50	Mismatching	FIPEC-24, 44%
269	LDF board	-	50	Mismatching	FIPEC-45, 42%
273	Phenolic foam	-	50	Mismatching	None
276	Pine	-	50	Mismatching	FIPEC-24, 59%
612	Fabric: 100% Cotton FR Treated; Interliner: Kevlar	CMHR Urethane Foam	50*	Mismatching	FIPEC-38, 36%
650	Fabric: 100% Wool	Polyether Foam	50*	Mismatching	FIPEC-35, 19%
656	Fabric: Leather	Polyether Foam	50*	Mismatching	FIPEC-39, 55%
1674	Carpet	Glue	50	Mismatching	FIPEC-33, 11%
1702	HPL compact	-	50	Mismatching	FIPEC-28, 37%
1720	HPL Melamine	polyester film	50	Mismatching	FIPEC-38, 25%
1760	Silicone rubber	-	50	Mismatching	FIPEC-26, 28%

* The imposed heat flux is assumed to be 50 kW/m^2 because it is absent in SP's database.

5.4 Validation to other material HRRs (Other methods)

The database of FIPEC project was conducted in accordance with the ISO 5660 therefore it is necessary that the input data must be obtained on the same standard procedure for comparability. However, the input interface of FIPECMATCH is open-end format therefore the input correctness depends on user's data and it is possible to input any kinds of data pattern. The reliability criterion is that FIPECMATCH must be able to distinguish whether or not the input is cable HRR conducted by ISO 5660 and select the correct database. If the input is not the cable HRR, the result should be mismatching.

To test the correctness, some input patterns were put into this software and the results are as follows.

5.4.1 Simple straight line pattern

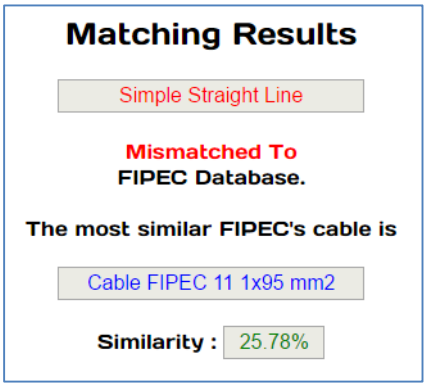

Figure 60 The simple straight line HRR matching result

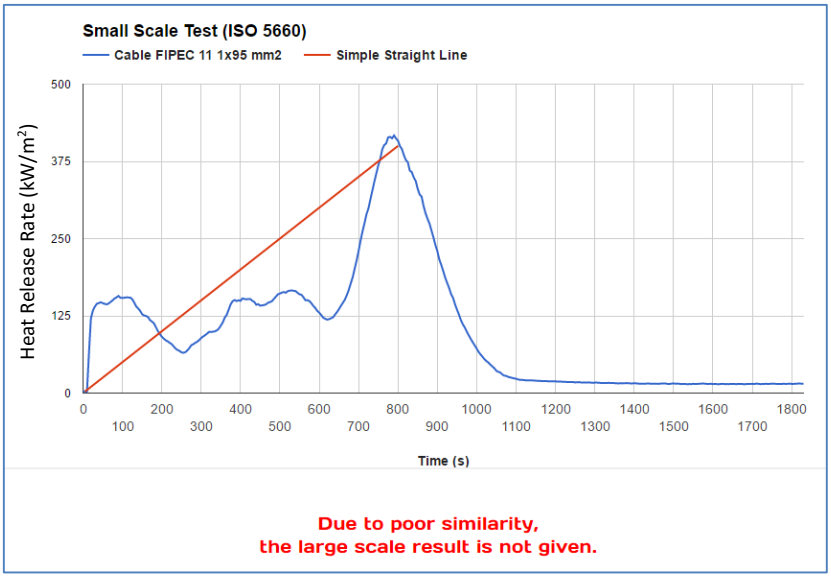

Figure 61 The simple straight line to FIPEC-11 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-11 is the most similar pattern, the similarity is poor with only 25.8% as shown in Figure 60. The HRR comparison graph in Figure 61 emphasizes the mismatching.

5.4.2 Ideal straight line pattern

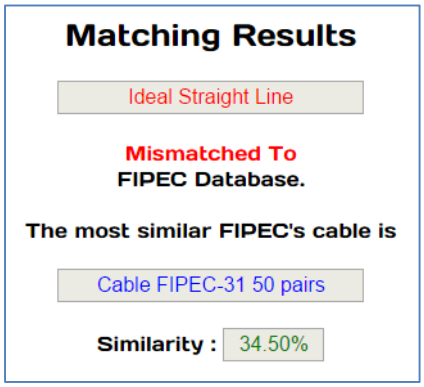

Figure 62 Ideal straight line HRR matching result

Figure 63 Ideal straight line to FIPEC-31 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-31 is the most similar pattern, the similarity is poor with only 34.5% as shown in Figure 62. The HRR comparison graph in Figure 63 emphasizes the mismatching.

5.4.3 Ideal t^2 line pattern

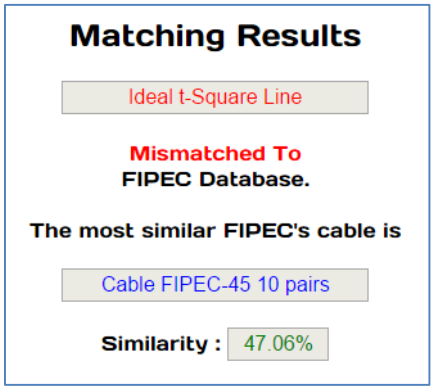

Figure 64 Ideal t^2 line HRR matching result

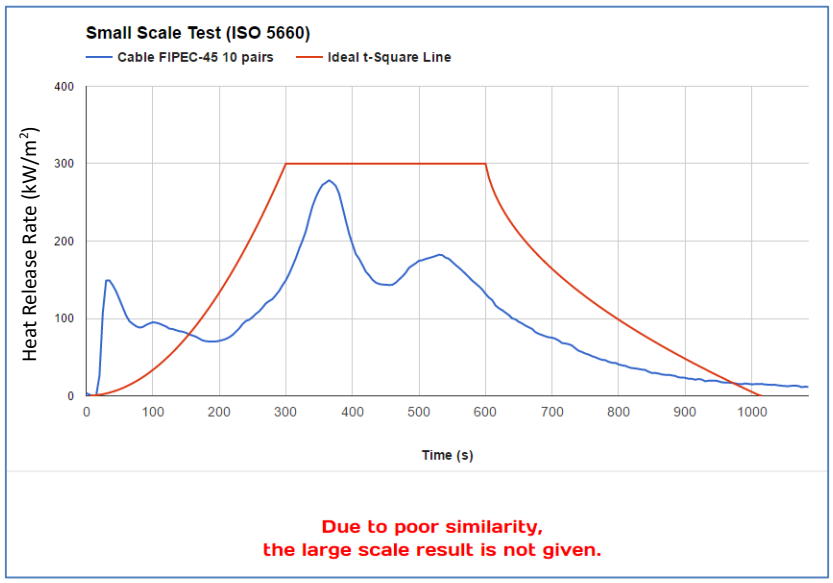

Figure 65 Ideal t^2 line pattern to FIPEC-45 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-45 is the most similar pattern, the similarity is poor with only 47.06% as shown in Figure 64. The HRR comparison graph in Figure 65 emphasizes the mismatching.

5.4.4 A small dining table HRR [9]

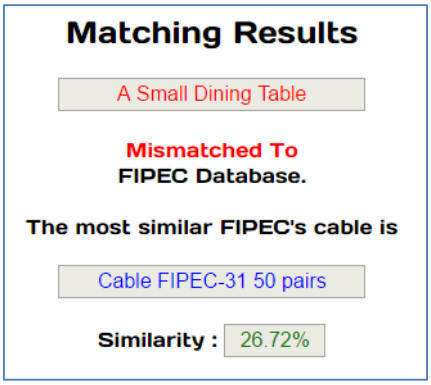

Figure 66 A small dining table HRR matching result

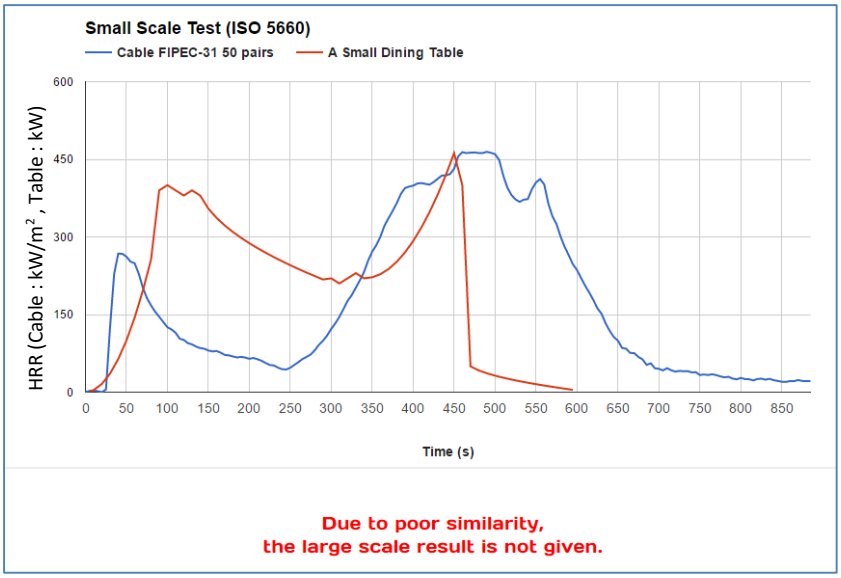

Figure 67 A small dining table to FIPEC-31 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-31 is the most similar pattern, the similarity is poor with only 26.7% as shown in Figure 66. The HRR comparison graph in Figure 67 emphasizes the mismatching.

5.4.5 A curtain HRR [9]

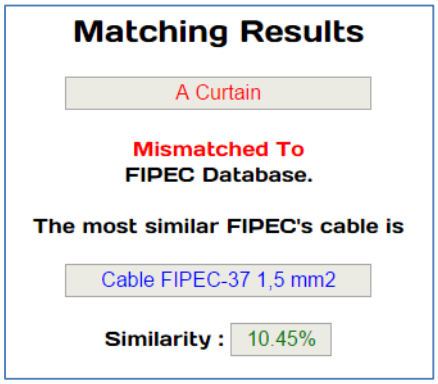

Figure 68 A curtain HRR matching result

Figure 69 A curtain to FIPEC-37 HRR comparison

The outcome turned out as expected, FIPECMATCH gave the result as mismatching. Although FIPEC-37 is the most similar pattern, the similarity is poor with only 10.5% as shown in Figure 68. The HRR comparison graph in Figure 69 emphasizes the mismatching.

6. Discussion

The FIPECMATCH's results in section 5 show a satisfactory reliability not only the verification but also the validation. However there are still some aspects to discuss in this section so as to achieve the maximum efficiency of this package.

Since the FIPEC's small-scale database was conducted in accordance with the ISO 5660, all inputs must be the result of the same standard procedure. This is considered as the first rule of using the FIPECMATCH otherwise the outcome will be meaningless even if the result is matched to the database. In section 5.4 Input varieties, the inputs of other materials such as a dining table and a curtain has been used as examples. These inputs were intended to show the performance that FIPECMATCH gave the mismatching result as the correct judgement because these inputs have a different HRR unit and were obtained by a different method. Moreover, the database is stored in the form of 5-second time step and as a result the input must be the same format or else the input and the database is incomparable and the output is useless. FIPECMATCH has provided the converter module to facilitate this difficulty.

If the input HRR is a raw fluctuate signal, it is necessary to setup the average line before putting it into this software because the FIPEC's database is stored as the 30-second average line. FIPECMATCH has provided this tool in separated module, which is called Smoother. Nevertheless, if the input is already the average signal, users would be able to put it in the input sheet directly.

The results in the verification section confirm the correctness of FIPECMATCH, for simple example if the modified input is multiplied by 0.9 to all time steps, the final calculated similarity should be 90% which it was proved in section 5.2. In addition, the similarity of the time translation cases should be lower than 100% and the more time difference, the lower similarity should be turned out. The results in section 5.2 coincide with this logic. For the multi-modification cases, both multiplier factor and time translation, the similarity should be lower than the percentage of the multiplier factor, because there are two reductions at the same time. For example, if the multiplier factor is 0.8 associated with 30 seconds earlier translation, the final similarity should be lower than 80%. The results in section 5.2 comply with this logic. It should be noted here that all modified cases were set up for verification purposes. It is not the real input case. For instance, the modified FIPEC-19 is not the input, which is intended to match with FIPEC-19 because the modified FIPEC-19 is not FIPEC-19 anymore. Matching to any database depends on the final calculated similarity which the highest similarity will be selected as the final solution therefore there is possibility that the modified FIPEC-19 will be matched with another database rather than FIPEC-19.

FIPECMATCH should give the matched result only for the cable HRR input, which is the basis of validation. All results in section 5.3 and 5.4 support this logic because FIPECMATCH has simple but two strong filters. The first filter captures the peak HRR and time to the peak in order to make the short list. All items in the database, which have the peak HRR and time to

the peak fall into the first filter region will be allocated in the short list. The bound values, which are ±70% for HRR and ±120 seconds for time to the peak were selected. These bound values are observed from the repeatability and reproducibility study in FIPEC project. It is found that if the same cable is tested at different time or different laboratory, the deviation is in these bound values. However, the bound values are not necessary to be strict for FIPECMATCH because the benefit of these values is only shortening the short list and acceleration of running process. These bound values are changeable by adjusting the software code depending on the complexity of the database.

It should be stated here that the bound values of the first filter are the parameters to calculate the so called FIGRA [10]. Instead of using it as the ratio product as the FIGRA, FIPECMATCH captures and records these value independently. Although the FIGRA is not the property of tested material because its value depends on the testing environment such as the imposed heat flux, for the same standard procedure, its value is almost constant. FIPECMATCH uses these values to seek the high potential matched database with the input.

The second filter examines the similarity of all items in the short list compared to the input data for all time steps. The highest similarity will be chosen to justify whether or not it is higher than 70%. If the similarity is equal to or higher than 70%, the pairs in comparison is deemed to be matched otherwise it is mismatching. The matching criterion of 70% is observed from the repeatability and reproducibility study in FIPEC project. Nevertheless, if there is an evidence that this value is not suitable, it is possible to adjust this value. The results in section 5.3 and 5.4 confirm that 70% is good value to distinguish the comparison since there is no other material which has the similarity higher than 60% as shown in Table2. The example case which material is pine, SP's ID : 276, has the similarity of 59% with FIPEC-24. This case is quantified as mismatching. Figure 70 emphasizes the FIPECMATCH's judgment.

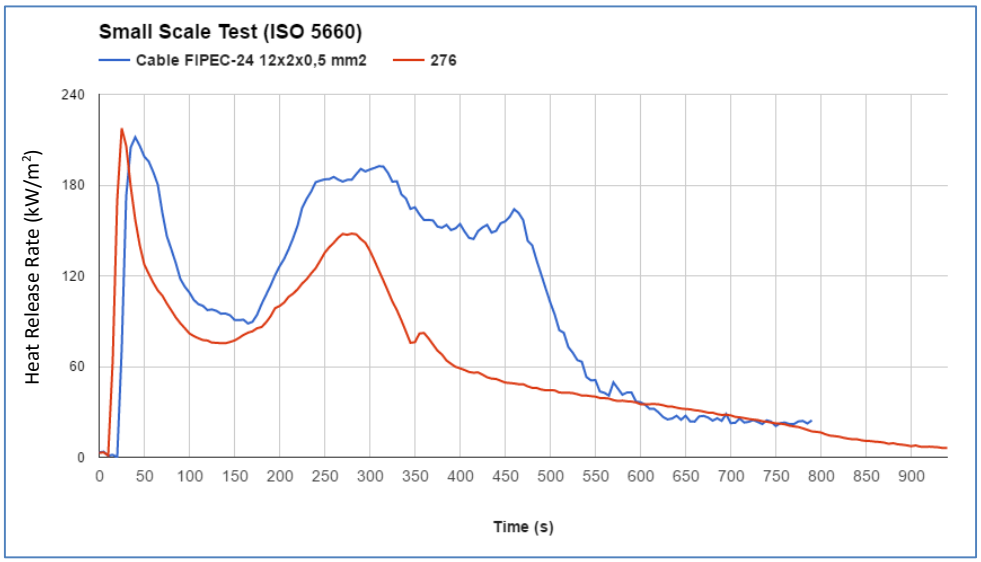

Figure 70 Pine and FIPEC-24 HRR comparison

Although pine and FIPEC-24 have the peak HRR and time to the peak in the vicinity of the first filter region, the second filter which is shape examiner works quite well because it can distinguish the pattern difference and gives only 59% of similarity.

However, it should be kept in mind that there is a small possibility for fault analysis because FIPECMATCH examines only the HRR pattern. If there are really similar HRRs among different materials, FIPECMATCH will match this pair together. If this situation occurs, the matching result is not reliable. The users have to perform the full-scale testing separately in order to get the correct result. In this case, the similar full-scale result should be expected. It will be more advantage, if the users share the information of this case to FIPECMATCH's staff through the sharing information module provided on the website.

7. Conclusions

The FIPEC project created the useful database for electric cable discipline and that database is kept in systematic storage ready for further development. In addition, FIPEC introduced new full-scale testing scenarios as a standard procedure for cable testing. This originates from the concept of matching HRR by means of comparison instead of mathematical correlation.

FIPECMATCH exploits the available resources of FIPEC to create new tool in fire safety field. The full-scale testing results can be found by the results of small-scale test as many researchers have been trying. The outstanding benefit of this tool is for cable manufacturers who want to test their new product whether or not it has its fire performance consistency. Having FIPECMATCH gives the economic solution because only the small-scale tests are needed. The fire performance of new cables can be checked as frequently as the regulator requires in order to guarantee that the fire safety standard is maintained.

The challenging further study is the complex cable combination as well as new complex full-scale arrangements. If the mixing ratio in a small-scale test corresponds to the same mixing ratio in a full-scale scenario, the matching concept can be applied. Moreover, it would be a great advantage for fire safety engineering if all cables in the world will be tested by the same protocol as in the FIPEC project and the results should be collected and stored in the database.

FIPECMATCH still needs further validation with new cable HRR so as to support its reliability to be the standard tool for determination of design fires for cables.

8. Acknowledgements

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Google Company provides the best and free server for all users over the world. It gives the opportunity and possibility to create new innovation whatever users need. Without Google, FIPECMATCH will never come true.

The author wants to respect his home country, Thailand where the studying abroad opportunity was given. The author promises to bring all knowledge back home in order to develop his home country.

The author is always aware of his family's patient being during two years of master term. It was long time enough to leave them behind. Now, it is the time to reunite and spend the rest of the life together.

Lastly, the author is delighted to invite anybody who is interested in fire safety world to join the IMFSE programme. During two years of IMFSE courses, student will have the marvellous experiences of exploration three universities or more. General engineers will transform to be the fire safety expert that is what the author can assure.

9. References

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10. Appendices

A1 : List of FIPECMATCH Database

Pair No	FIPEC Code	Obect	Material 1	Material 2	Flux (kW/Sqm)
1	Cable FIPEC 03-1x150 mm2	Medium Voltage 12/20 kV	PVC	XLPE	35
2	Cable FIPEC 03-1x150 mm2	Medium Voltage 12/20 kV	PVC	XLPE	50
3	Cable FIPEC 03-1x150 mm2	Medium Voltage 12/20 kV	PVC	XLPE	75
4	Cable FIPEC 04 1x150 mm2	Medium Voltage 12/20 kV	PE	XLPE	35
5	Cable FIPEC 04 1x150 mm2	Medium Voltage 12/20 kV	PE	XLPE	50
6	Cable FIPEC 04 1x150 mm2	Medium Voltage 12/20 kV	PE	XLPE	75
7	Cable FIPEC 05 3x1x150 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	35
8	Cable FIPEC 05 3x1x150 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	50
9	Cable FIPEC 05 3x1x150 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	75
10	Cable FIPEC 06 3x1x150 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	35
11	Cable FIPEC 06 3x1x150 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	50
12	Cable FIPEC 06 3x1x150 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	75
13	Cable FIPEC 07 3x1x150 mm2	Low Voltage 0,6/1 kV	Polyolefin	XLPE	35
14	Cable FIPEC 07 3x1x150 mm2	Low Voltage 0,6/1 kV	Polyolefin	XLPE	50
15	Cable FIPEC 07 3x1x150 mm2	Low Voltage 0,6/1 kV	Polyolefin	XLPE	75
16	Cable FIPEC 08 3x1x150 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	35
17	Cable FIPEC 08 3x1x150 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	50
18	Cable FIPEC 08 3x1x150 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	75
19	Cable FIPEC 09 3x1x150 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	35
20	Cable FIPEC 09 3x1x150 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	50
21	Cable FIPEC 09 3x1x150 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	75
22	Cable FIPEC 10 3x1x150 mm2	Low Voltage 0,6/1 kV	POlyolefin	XLPE	35
23	Cable FIPEC 10 3x1x150 mm2	Low Voltage 0,6/1 kV	POlyolefin	XLPE	50
24	Cable FIPEC 10 3x1x150 mm2	Low Voltage 0,6/1 kV	POlyolefin	XLPE	75
25	Cable FIPEC 11 1x95 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	35
26	Cable FIPEC 11 1x95 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	50
27	Cable FIPEC 11 1x95 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	75
28	Cable FIPEC 12 1x95 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	35
29	Cable FIPEC 12 1x95 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	50
30	Cable FIPEC 12 1x95 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	75
31	Cable FIPEC 13 1x95 mm2	Low Voltage 0,6/1 kV	Polyolefin	XLPE	35
32	Cable FIPEC 13 1x95 mm2	Low Voltage 0,6/1 kV	Polyolefin	XLPE	50
33	Cable FIPEC 13 1x95 mm2	Low Voltage 0,6/1 kV	Polyolefin	XLPE	75
34	cable FIPEC-14 1x95 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	35
35	cable FIPEC-14 1x95 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	50
36	cable FIPEC-14 1x95 mm2	Low Voltage 0,6/1 kV	PVC	XLPE	75
37	cable FIPEC-15 1x95 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	35
38	cable FIPEC-15 1x95 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	50
39	cable FIPEC-15 1x95 mm2	Low Voltage 0,6/1 kV	RPPVC	XLPE	75
40	cable FIPEC-16 1x95 mm2	Low Voltage 0,6/1 kV	Polyolefin	XLPE	35
41	cable FIPEC-16 1x95 mm2	Low Voltage 0,6/1 kV	Polyolefin	XLPE	50
42	cable FIPEC-16 1x95 mm2	Low Voltage 0,6/1 kV	Polyolefin	XLPE	75
43	Cable FIPEC 17 3x50 mm2	Low Voltage 0,6/1 kV	Polyolefin	EPR	35
44	Cable FIPEC 17 3x50 mm2	Low Voltage 0,6/1 kV	Polyolefin	EPR	50
45	Cable FIPEC 17 3x50 mm2	Low Voltage 0,6/1 kV	Polyolefin	EPR	75
46	Cable FIPEC 18 3x50 mm2	Low Voltage 0,6/1 kV	PVC	EPR	35
47	Cable FIPEC 18 3x50 mm2	Low Voltage 0,6/1 kV	PVC	EPR	50
48	Cable FIPEC 18 3x50 mm2	Low Voltage 0,6/1 kV	PVC	EPR	75
49	Cable FIPEC-19 3x50 mm2	Low Voltage 0,6/1 kV	ZHPolyolefin	XLPE	35
50	Cable FIPEC-19 3x50 mm2	Low Voltage 0,6/1 kV	ZHPolyolefin	XLPE	50
51	Cable FIPEC-19 3x50 mm2	Low Voltage 0,6/1 kV	ZHPolyolefin	XLPE	75
52	Cable FIPEC 20 7x2.5 mm2	Low Voltage 0,6/1 kV	Polyolefin	EPR	35
53	Cable FIPEC 20 7x2.5 mm2	Low Voltage 0,6/1 kV	Polyolefin	EPR	50
54	Cable FIPEC 20 7x2.5 mm2	Low Voltage 0,6/1 kV	Polyolefin	EPR	75

Pair No	FIPEC Code	Obect	Material 1	Material 2	Flux (kW/Sqm)
55	Cable FIPEC 21 7x2.5 mm2	Low Voltage 0,6/1 kV	RPPVC	EPR	35
56	Cable FIPEC 21 7x2.5 mm2	Low Voltage 0,6/1 kV	RPPVC	EPR	50
57	Cable FIPEC 21 7x2.5 mm2	Low Voltage 0,6/1 kV	RPPVC	EPR	75
58	Cable FIPEC-22 7x2.5 mm2	Low Voltage 0,6/1 kV	ZHPolyolefin	XLPE	35
59	Cable FIPEC-22 7x2.5 mm2	Low Voltage 0,6/1 kV	ZHPolyolefin	XLPE	50
60	Cable FIPEC-22 7x2.5 mm2	Low Voltage 0,6/1 kV	ZHPolyolefin	XLPE	75
61	Cable FIPEC 23 24x1x1.5 mm2	Data cable	PVC	PVC	35
62	Cable FIPEC 23 24x1x1.5 mm2	Data cable	PVC	PVC	50
63	Cable FIPEC 23 24x1x1.5 mm2	Data cable	PVC	PVC	75
64	Cable FIPEC-24 12x2x0,5 mm2	Data Cable	PVC	PVC	35
65	Cable FIPEC-24 12x2x0,5 mm2	Data Cable	PVC	PVC	50
66	Cable FIPEC-24 12x2x0,5 mm2	Medium Voltage 12/20 kV	PVC	PVC	75
67	Cable FIPEC-25 8x2x0,5 mm2	Data Cable	RPPVC	PVC	35
68	Cable FIPEC-25 8x2x0,5 mm2	Data Cable	RPPVC	PVC	50
69	Cable FIPEC-25 8x2x0,5 mm2	Data Cable	RPPVC	PVC	75
70	Cable FIPEC 26 1x3x1.5 mm2	Data cable	PVC	PVC	35
71	Cable FIPEC 26 1x3x1.5 mm2	Data cable	PVC	PVC	50
72	Cable FIPEC 26 1x3x1.5 mm2	Data cable	PVC	PVC	75
73	Cable FIPEC 28 1x3x1 mm2	Data Cable	PVC	PVC	35
74	Cable FIPEC 28 1x3x1 mm2	Data Cable	PVC	PVC	50
75	Cable FIPEC 28 1x3x1 mm2	Data Cable	PVC	PVC	75
76	Cable FIPEC-29 10 pairs	Telephone Cable	PVC	PE	35
77	Cable FIPEC-29 10 pairs	Telephone Cable	PVC	PE	50
78	Cable FIPEC-29 10 pairs	Telephone Cable	PVC	PE	75
79	Cable FIPEC-30 10 pairs	Telephone cable	PVC	PVC	35
80	Cable FIPEC-30 10 pairs	Telephone cable	PVC	PVC	50
81	Cable FIPEC-30 10 pairs	Telephone cable	PVC	PVC	75
82	Cable FIPEC-31 50 pairs	Telephone Cable	PVC	PE	35
83	Cable FIPEC-31 50 pairs	Telephone Cable	PVC	PE	50
84	Cable FIPEC-31 50 pairs	Telephone Cable	PVC	PE	75
85	Cable FIPEC-32 50 pairs	Telephone cable	PVC	PVC	35
86	Cable FIPEC-32 50 pairs	Telephone cable	PVC	PVC	50
87	Cable FIPEC-32 50 pairs	Telephone cable	PVC	PVC	75
88	Cable FIPEC-33 1,5 mm2	Wire		PVC	35
89	Cable FIPEC-33 1,5 mm2	Wire		PVC	50
90	Cable FIPEC-33 1,5 mm2	Wire		PVC	75
91	Cable FIPEC 34 1.50 mm2	Wires		RPPVC	35
92	Cable FIPEC 34 1.50 mm2	Wires		RPPVC	50
93	Cable FIPEC 34 1.50 mm2	Wires		RPPVC	75
94	Cable FIPEC-35 1,5 mm2	Wire		PVDF	35
95	Cable FIPEC-35 1,5 mm2	Wire		PVDF	50
96	Cable FIPEC-35 1,5 mm2	Wire		PVDF	75
97	Cable FIPEC-36 1,5 mm2	Wire		Polyester	35
98	Cable FIPEC-36 1,5 mm2	Wire		Polyester	50
99	Cable FIPEC-36 1,5 mm2	Wire		Polyester	75
100	Cable FIPEC-37 1,5 mm2	Wire		Polyolefin	35
101	Cable FIPEC-37 1,5 mm2	Wire		Polyolefin	50
102	Cable FIPEC-37 1,5 mm2	Wire		Polyolefin	75
103	cable FIPEC-38 4x2x0,2 mm2	Data cable	RPPVC	PEF	35
104	cable FIPEC-38 4x2x0,2 mm2	Data cable	RPPVC	PEF	50
105	cable FIPEC-38 4x2x0,2 mm2	Data cable	RPPVC	PEF	75
106	Cable FIPEC 39 75 Ohm	Coax	PVC	PE	35
107	Cable FIPEC 39 75 Ohm	Coax	PVC	PE	50
108	Cable FIPEC 39 75 Ohm	Coax	PVC	PE	75

Pair No	FIPEC Code	Obect	Material 1	Material 2	Flux (kW/Sqm)
109	Cable FIPEC 40 75 Ohm	Coax	PVC	PE	35
110	Cable FIPEC 40 75 Ohm	Coax	PVC	PE	50
111	Cable FIPEC 40 75 Ohm	Coax	PVC	PE	75
112	Cable FIPEC-41 multiple	Optical cable	Polyolefin	PA	35
113	Cable FIPEC-41 multiple	Optical cable	Polyolefin	PA	50
114	Cable FIPEC-41 multiple	Optical cable	Polyolefin	PA	75
115	Cable FIPEC-42 Single	Optical cable	Polyolefin	PA	35
116	Cable FIPEC-42 Single	Optical cable	Polyolefin	PA	50
117	Cable FIPEC-42 Single	Optical cable	Polyolefin	PA	75
118	Cable FIPEC-45 10 pairs	Telephone cable	PVC	PE	35
119	Cable FIPEC-45 10 pairs	Telephone cable	PVC	PE	50
120	Cable FIPEC-45 10 pairs	Telephone cable	PVC	PE	75
121	Cable FIPEC-46 50 pairs	Telephone cable	PVC	PE	35
122	Cable FIPEC-46 50 pairs	Telephone cable	PVC	PE	50
123	Cable FIPEC-46 50 pairs	Telephone cable	PVC	PE	75
124	Cable FIPEC 51 1x3x1.5 mm2	Data Cable	Polyolefin	PP	35
125	Cable FIPEC 51 1x3x1.5 mm2	Data Cable	Polyolefin	PP	50
126	Cable FIPEC 51 1x3x1.5 mm2	Data Cable	Polyolefin	PP	75

A2 : FIGRA

FIGRA stands for “Fire Growth Rate” which is used to describe the burning characteristic of materials [10]. When this parameter is obtained from the certain test procedure, for instance FIPEC, it can be used as one of the criteria to classify materials such as electric cables. Furthermore, this parameter is used to predict the testing results between different scales of testing as well as fire propagation as the one of parameter in complex mathematical correlations [4].

FIGRA is defined as the proportion between the peak HRR (W) and the time to the peak (s). The HRR must be the 30-second average value whereas the time to the peak is the period of time from the ignition until the peak. The following example shows more details of FIGRA calculation.

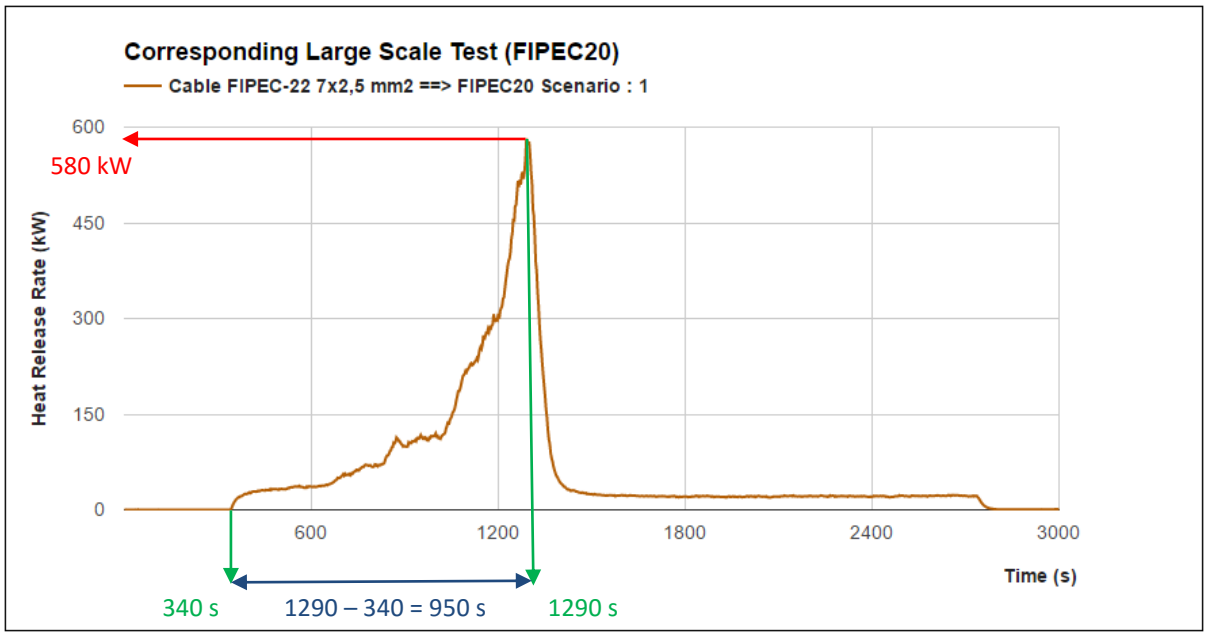

Figure 71 FIGRA calculation

$$\text{FIGRA} = \frac{\text{Peak HRR (W)}}{\text{Time to the peak (s)}}$$

$$= \frac{580 \times 1000 \text{ W}}{950 \text{ s}}$$

$$= 610 \text{ W/s}$$