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RAPPORT

Birgit Östman, Lazaros Tsantaridis

Correlations between Cone Calorimeter Data and Time to Flashover in the Room Fire test

Paper presented at the First Japan Symposium on Heat Release and Fire Hazard, Tsukuba, Japan, May 1993

Trätek

INSTITUTET FÖR TRÄTEKNISK FORSKNING

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FOREWORD

This paper was presented at the First Japan Symposium on Heat Release and Fire Hazard held in Tsukuba, Japan, May 1993. It appears in the Proceedings from the Symposium.

An appendix is added with tables of the products tested.

SAMMANFATTNING - SWEDISH SUMMARY

Ett enkelt empiriskt samband har utvecklats för att beräkna tiden till övertändning i ett rum klätt med olika vägg- och takmaterial vid fullskalig rumsbrandprovning. Det baseras på provning av 28 olika ytmaterial. Bland dessa fanns både träbaserade och oorganiska material med och utan ytskikt samt syntetiska material.

För beräkningen används fysikaliskt väldefinierade data från en ny småskalig brandprovningsmetod den s.k. konkalorimetern. De standarddata som används är tid till antändning och värmeutveckling under brand. Dessutom inkluderas ytmaterialens densitet, som är ett enkelt mått på materialens termiska tröghet. Sambandet beskrivs av ekvationen:

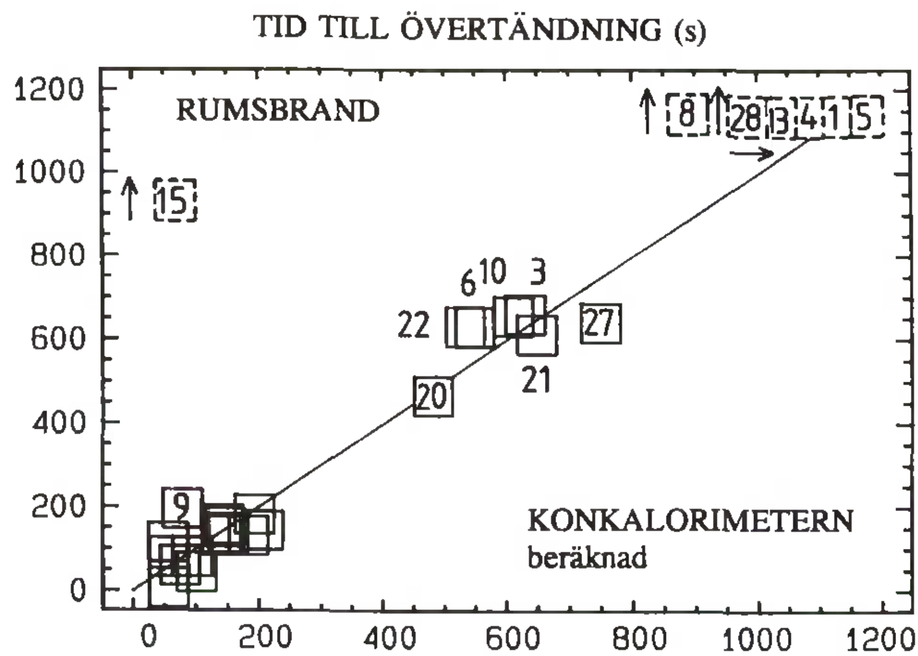
$$t_{fo} = a \frac{t_{ig}^{0,25} \rho^{1,72}}{A^{1,30}} + b$$

där

t_{fo}	=	tid till övertändning vid rumsbrandprovning, s
t_{ig}	=	tid till antändning vid 50 kW/m^2 i konkalorimetern, s
A	=	värmeutveckling under 5 min efter antändning vid 50 kW/m^2 i konkalorimetern, J/m^2
ρ	=	ytmaterialets densitet, kg/m^3
a	=	konstant, 0,0717 (J/m^2)^{1,30} (kg/m^3)$^{-1,72}$ s^{0,75}
b	=	konstant, 56,6 s

Korrelationskoefficienten för sambandet är 0,974. Det gäller för de 21 ytmaterial som ledde till övertändning vid rumsbrandprovning då materialen applicerades på både väggar och i tak. Sju av de 28 materialen ledde inte till övertändning vid rumsbrandprovning och kan därför inte jämföras direkt. Deras beräknade tid till övertändning blir längre än för övriga material, vilket överensstämmer med provningen. Resultaten illustreras i figur på nästa sida.

Arbetet är en vidareutveckling av en tidigare ansats då 13 ytmaterial ingick. De samband som erhålls med bara 13 material och med alla 28 materialen är mycket lika, vilket är en stark indikation på att det angivna sambandet ger en pålitlig uppskattning av tiden till övertändning.



Uppmätt tid till övertändning vid rumsbrandprovning som funktion av beräknad tid till övertändning enligt data från konkalorimetern för 28 olika vägg- och takmaterial. Korrelationskoefficienten för sambandet är 0,974. (Ytmaterialen har i mån av plats identifierats med nummer, som återfinns i Appendix. Streckade kvadrater anger material som inte övertände vid rumsbrandprovning. Nr 15 är ett gränsfall, som inte övertände vid två provningar, men som övertände redan efter ca 1 min vid en tredje provning.)

CORRELATION BETWEEN CONE CALORIMETER DATA AND TIME TO FLASHOVER IN THE ROOM FIRE TEST

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ABSTRACT

The correlations are based on linear regressions between data as time to ignition and total heat release in the cone calorimeter and time to flashover in the room fire test. They are a further development of an earlier approach which has been modified and extended to a wider range of surface linings. The correlations apply so far only to surface linings on both walls and ceilings. When the density of the linings is included, the correlations are improved significantly.

The new correlations are based on data readily available from the cone calorimeter test at one heat flux level, 50 kW/m^2. The correlation coefficent for the basic relationship including the density of the linings is now 0.98 when applied to the 13 linings earlier investigated. This is slightly better than the earlier study in which the best correlation coefficient was 0.96. When applied to 28 linings, the correlation coefficient remains about the same, 0.97.

Very similar regression equations have been obtained when analysing only 13 products and all 28 products. This is a strong indication of the general predictive capacity of this approach. The inclusion of other data like thickness of linings or mass loss during fire does not improve the correlation coefficients. The approach is quite straightforward and simple. Still, it has proved to supply a useful prediction which is valid also for an extended range of linings.

1. INTRODUCTION

The early fire behaviour of products is important in many aspects of fire safety. New fire tests have been developed e.g. within ISO in order to determine the fire behaviour of surface lining products in a more elaborate way than the present national fire test methods. The new tests are both in small and full scale. Small-scale tests are necessary as practical tools. Full-scale tests are generally considered to be more reliable and are needed to validate the small-scale tests. A full-scale standard room fire test is widely used /1/. Among the small-scale tests, the cone calorimeter /2/ is considered to be the most useful and universal instrument. However, the relationships between small-scale and full-scale fire tests are of major interest. Early attempts have been demonstrated /10, 11/. Several empirical correlations or models have been proposed /12, 13, 14, 15/. In other studies, parameters as flame spread have been included for more advanced modelling /16, 17, 18/.

In this study, an earlier empirical approach /9/ will be modified and extended to a wider range of products.

2. EXPERIMENTAL

2.1 Tested products

Three sets of building products have been included: a new set of 11 Eurefic products /3,6/, another new set of 4 products from the Nordic round robin within ISO TC 92/SC 1/WG 7 for the room fire test /4,7/ and an old set of 13 products earlier frequently used for fire studies in Scandinavia /5,8/. Thus, a total of 28 building products are included in this paper, see Table 1.

2.2 Test methods

The room fire tests have been performed according to ISO 9705 /1/ at different Nordic laboratories: for the 11 EUREFIC and the 4 Nordic round robin products at the national fire laboratories in Finland, Norway and Sweden /3,4/ and for the 13 Scandinavian products at the Swedish National Testing Institute /5/. All tests have been performed with both the walls and the ceiling covered with the lining products. An ignition source of 100 kW is placed in one of the inner corners. If flashover does not occur within 10 minutes, the ignition source is raised to 300 kW. The maximum test time is 20 minutes. A large number of parameters are measured, but in this paper only the time to flashover will be used for characterizing the fire behaviour of the tested products.

The cone calorimeter tests have been performed according to ISO 5660 /2/ with horizontal specimens. All products have been tested by using the recommended stainless steel retainer frame /6,7,8/ and with a low density (65 kg/m^3) fiber blanket as backing material according to the standard. Only data at a heat flux level of 50 kW/m^2 have been chosen, since all products ignite at 50 kW/m^2, but not at 25 and 35 kW/m^2. The total heat release, the time to ignition and the mass loss were the parameters used in this paper.

3. RELATIONS BETWEEN THE CONE CALORIMETER AND THE ROOM FIRE TEST

The aim has been to find a relation between basic parameters from the cone calorimeter and time to flashover in the room fire test. It is an extension of an earlier approach /9/. The cone calorimeter parameters used in this paper are based on data available from the standard test procedure at one heat flux level, 50 kW/m^2. They are calculated from ignition to 5 minutes after ignition. The time to flashover in the room fire test is defined as the time to reach 1 MW heat release. All data are listed in Table 1.

The relations are all of the form $y = ax + b$, where y is time to flashover in the room fire test and x is an expression based on different cone calorimeter parameters. The different parameters x have different exponents, see Table 2. The constants a and b and the exponents have been determined by linear regression analyses using a standard statistics computer program.

The analyses are made both for the 13 Scandinavian products and for all the 28 products. This makes it possible to compare the results with the earlier approach for the 13 products /9/. One product, no 28, of the 13 Scandinavian products did not reach flashover. Seven products, nos. 1, 4, 5, 8, 13, 15, 28, of all the 28 products did not reach flashover. These products are therefore not included in the analyses.

Table 1. **Time to flashover in the room fire test and Cone calorimeter data** with retainer frame at 50 kW/m² and horizontal orientation.

Products	Room test Time to flashover	Cone calorimeter Time to ignition	THR_{300}[1)]	Mass[2)] $loss_{300}$
	min:s	s	MJ/m²	kg 10^{-3}
1. Painted gypsum paper plasterboard	> 20	47	7.0	10.7
2. Ordinary birch plywood	2:30	30	38.0	37.0
3. Textile wallcovering on gypsum paper plasterboard	11:00	25	12.8	14.8
4. Melamine-faced high-density non-combustible board	> 20	29	9.8	17.0
5. Plastic-faced steel sheet on mineral wool	> 20	53	3.7	1.9
6. FR particle board, type B1	10:30	21	10.4	18.7
7. Combustible-faced mineral wool	1:20	5	4.0	0.9
8. FR particle board	> 20	700	17.0	13.8
9. Plastic-faced steel sheet on polyurethane foam	3:15	19	17.2	14.2
10. PVC-wallcarpet on gypsum paper plasterboard	10:55	15	11.9	15.3
11. FR extruded polystyrene foam	1:20	31	22.3	7.8
12. Birch plywood	2:17	28	35.5	33.8
13. FR plywood	> 20	469	8.7	4.9
14. Melamine-faced particle board	3:02	34	32.9	23.0
15. FR polystyrene foam	> 20	25	24.2	6.8
16. Particle board	2:37	34	45.9	32.1
17. Insulating wood fiber board	0:59	12	33.2	22.3
18. Medium-density wood fiber board	2:11	31	32.6	31.5
19. Wood panel, spruce	2:11	20	25.0	25.1
20. Melamine-faced particle board	7:45	41	19.8	25.1
21. Plastic wallcovering on gypsum board	10:11	10	9.2	11.9
22. Textile wallcovering on gypsum board	10:29	20	12.1	14.7
23. Textile wallcovering on rockwool	0:43	11	8.5	4.6
24. Paper wallcovering on particle board	2:23	33	29.8	29.3
25. Rigid polyurethane foam	0:06	2	17.4	8.9
26. Expanded polystyrene	1:55	39	32.8	9.9
27. Paper wallcovering on gypsum board	10:40	21	9.4	10.5
28. Gypsum board	> 20	34	6.7	9.1

1) THR_{300} = total heat release during 5 minutes after ignition (calculated per 0.01 m² sample area).

2) Mass $loss_{300}$ = mass loss during 5 minutes after ignition.

Table 2. **Correlation coefficients, r,** between different cone calorimeter parameters and time to flashover in the room fire test.

Regression equation nos.	No of products reaching flashover	Expressions based on cone calorimeter parameters x*	Constants in eqs. 1-10 a	b	Correlation coefficients r
1.	12	$t_{ig}^{1.05}/A^{1.43}$	$6.846\ 10^{2}$	-12.8	0.784
2.	12	$t_{ig}^{0.14}\ \rho^{2.20}/A^{1.18}$	$2.977\ 10^{-3}$	45.3	0.980
3.	12	$t_{ig}^{0.42}/(A^{1.39}\ \delta^{1.30})$	$1.807\ 10^{1}$	-28.7	0.938
4.	12	$t_{ig}^{0.61}\ m^{1.75}/(A^{3.29}\ \delta^{0.89})$	$1.083\ 10^{7}$	32.8	0.981
5.	12	$t_{ig}^{0.71}\ m^{2.52}/A^{4.09}$	$7.016\ 10^{10}$	45.9	0.981
6.	21	$t_{ig}^{1.36}/A^{1.50}$	$3.144\ 10^{2}$	-8.5	0.742
7.	21	$t_{ig}^{0.25}\ \rho^{1.72}/A^{1.30}$	$7.171\ 10^{-2}$	56.6	0.974
8.	21	$t_{ig}^{0.62}/(A^{1.77}\ \delta^{2.44})$	$1.772\ 10^{-1}$	32.3	0.913
9.	21	$t_{ig}^{0.50}\ m^{1.06}/(A^{2.74}\ \delta^{2.46})$	$2.186\ 10^{2}$	58.3	0.957
10.	21	$t_{ig}^{0.23}\ m^{0.57}/A^{1.07}$	$6.170\ 10^{4}$	-249	0.916

* Linear regressions of the form y = ax + b, where y is time to flashover in room fire test and x is an expression based on different cone calorimeter parameters at 50 kW/m^2:

t_{ig}	time to ignition, s
A	total heat release (THR_{300}), J/m^2
m	mass loss, kg
ρ	density, kg/m^3
δ	thickness, m

\ prediction based on only total heat release and time to ignition provides low correlation coefficients,).74 - 0.78, see regression eqs. 1 and 6 in Table 2. Better correlation coefficients, 0.97 - 0.98, are obtained if the density is considered as well, see regression eqs. 2 and 7. After that no further mprovments have been found when including all 28 products. If both the thickness and the mass loss ire included instead of density, the correlation coefficient remains about the same, 0.981, for the 13 products, but is slightly decreased to 0.957 for all 28 products, see regression eqs. 4 and 9. When only he mass loss is included instead of density, the correlation is the same, 0.981, for the 13 products but lecreased to 0.916 for all 28 products, see regression eqs. 5 and 10. When only the thickness is included nstead of density the correlation coefficients are decreased in both cases, regression eqs. 3 and 8.

Three predictive expressions in Table 2 give correlation coefficients of about 0.98 for the 13 Scandinavian products. Only one of these gives a good correlation coefficient also for all the 28 products,).974. It is the correlation for total heat release, time to ignition and density, regression eq. 7, which s described by the equation:

$$t_{fo} = a \frac{t_{ig}^{0.25} \rho^{1.72}}{A^{1.30}} + b$$

vhere t_{fo} = time to flashover in room fire test, s
t_{ig} = time to ignition in cone calorimeter at 50 kW/m^2, s
A = total heat release during 5 minutes after ignition at 50 kW/m^2 (THR_{300}), J/m^2
ρ = density, kg/m^3
a = constant, 0.0717 $(J/m^2)^{1.30}$ $(kg/m^3)^{-1.72}$ $s^{0.75}$
b = constant, 56.6 s

Some of the regressions are also given in Figure 1 in which the products not reaching flashover in the room fire test are marked by dashed squares. Those products get in most cases predicted times to flashover which are longer than 20 minutes. When evaluating the best predictive expression, eq. 7, there are two exceptions: product no 15, a fire retardant polystyrene foam, and product no 8, a fire retardant particle board. Product no 15 gets a short predicted time to flashover, only about one minute, but was hard to test in the room fire tests /4/. In two of the room fire tests it did not reach flashover, but in a third test it flashed over in 67 seconds. The reason for these differencies is most probably differencies n the methods of glueing the sample to the substrate /4/. It is thus quite understandable that its behaviour s hard to predict. Product no 8 gets about 15 minutes in predicted time to flashover which is more reasonable. For the other five products not reaching flashover in the room fire test, the predicted time o flashover is more than 20 minutes.

The results are also presented in Figure 2 as simple stepwise ranking orders according to regression eq. 2 for the 13 products and to eq. 7 for the 28 products. Ranking order 1 means longest time to flashover. t is obvious that the agreement is quite good for all products with the exception of product no 15, as nentioned above. Product no 9, a plastic-faced steel sheet on polyurethane foam, is also a slight outlier.

The predictive eq. 2 obtained for the 13 Scandinavian products seems to fit also all the 28 products surprisingly well as shown in Figure 3. The correlation coefficient is 0.971, which should be compared with 0.974 for eq. 7. The main differencies compared to eq. 7 in Figure 1 are that product nos. 8 and 13 get a better agreement with the experimental data in Figure 1. All other products get about the same predictions. Eq. 7 should therefore be preferred.

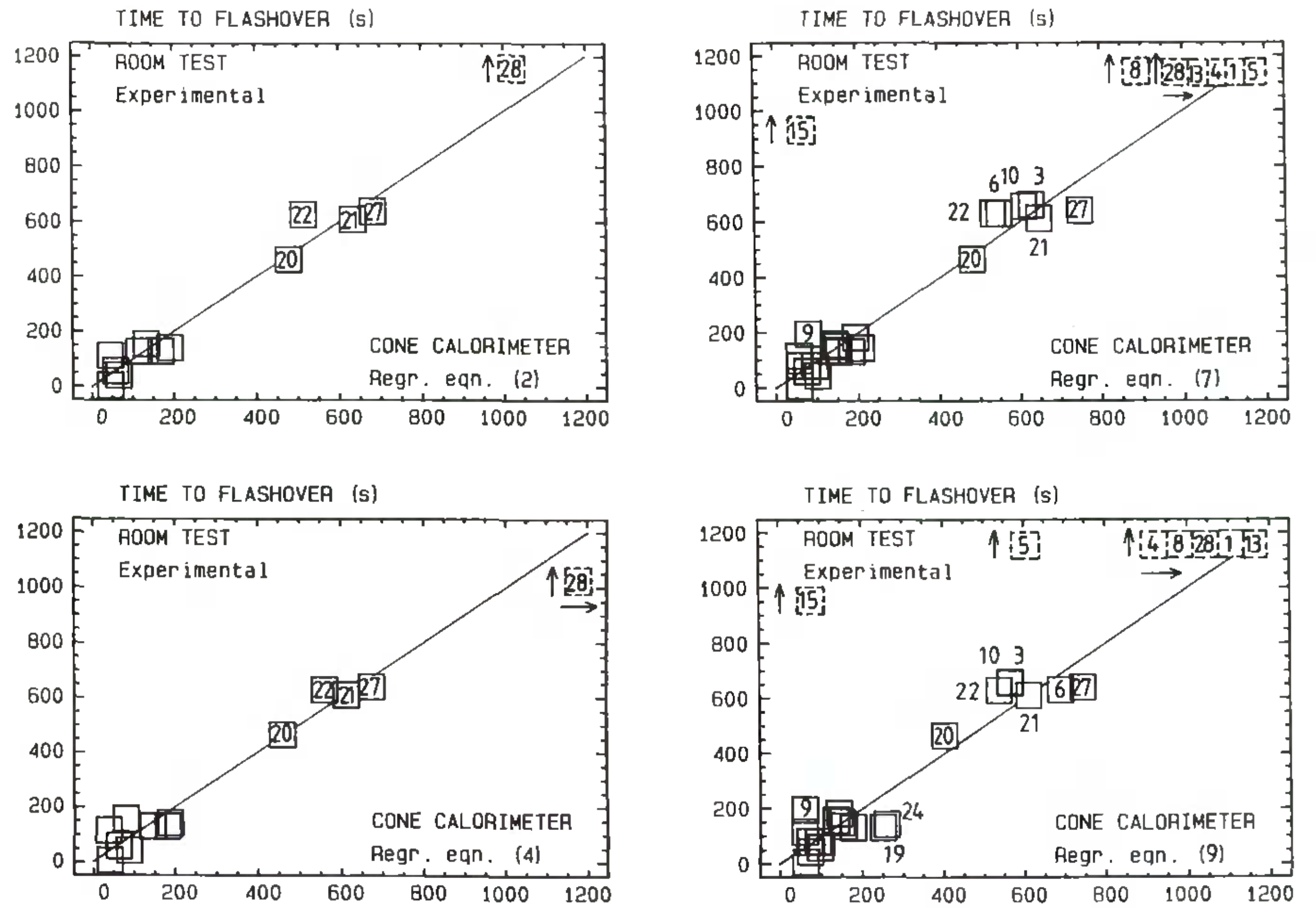

Figure 1.
Time to flashover in the room fire test vs predicted time to flashover from cone calorimeter data according to different regression equations, see Table 2. To the left for the 13 Scandinavian products and to the right for all 28 products. Where possible the products are identified by product numbers. One product, no 28, of the 13 and seven products, nos. 1, 4, 5, 8, 13, 15, 28, of the 28 products did not reach flashover in the room fire test and are marked by dashed squares.

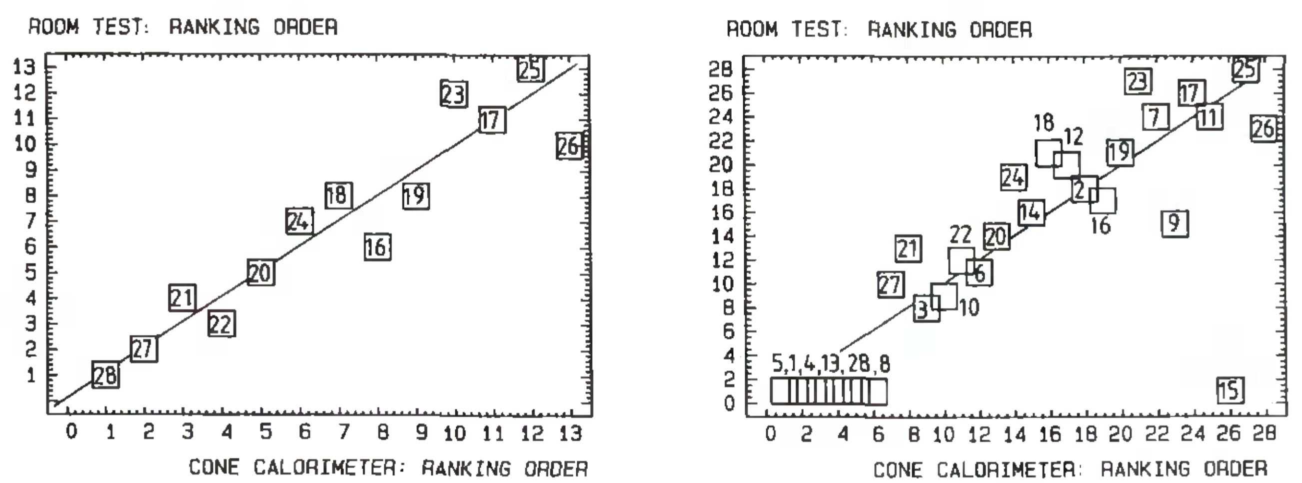

Figure 2.
Stepwise ranking order of products according to the room fire test and cone calorimeter predictions. Ranking order 1 means longest time to flashover. To the left for the 13 Scandinavian products according to eq.2, to the right for all 28 products according to eq. 7.

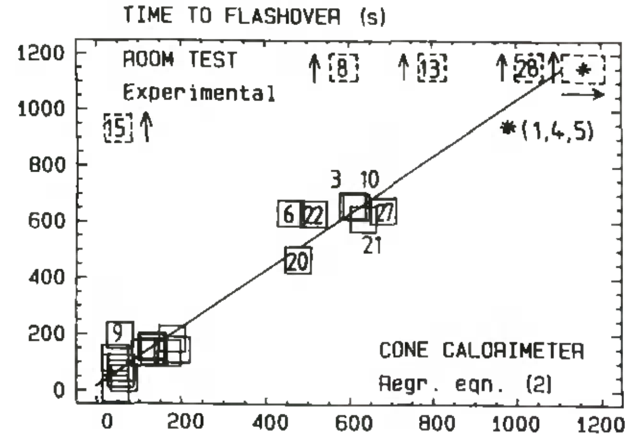

Figure 3.
The regression eq. 2 for the 13 products fits also all the 28 products fairly well. The correlation coefficient is in this case 0.971, which should be compared with 0.974 for eq. 7 based on all 28 products.
(See upper diagram to the right in Figure 1)

. CONCLUSIONS

. very simple linear regression equation has been developed for predicting the time to flashover in the oom fire test based on cone calorimeter data. The equation is thus based on basic physical parameters ut does not assume any specific physical or theoretical model of the fire.

he cone calorimeter data used are time to ignition and total heat release during 5 minutes after ignition, oth measured at an irradiance of 50 kW/m^2. Those cone calorimeter data are combined with the density f the lining product, which reflects the influence of the thermal inertia on the early fire growth. Other ata like thickness of linings or mass loss during fire do not improve the regressions when all products re included.

he approach is a modification of an earlier study with 13 products. It is also an extension to another 5 products, i.e. totally 28 products. Very similar regression equations have been obtained when nalysing only 13 products and all 28 products. This is a strong indication of the general predictive apacity of this approach.

he regression equation can be simplified to

$$t_{fo} = 0.07 \frac{t_{ig}^{0.25} \, \rho^{1.7}}{A^{1.3}} + 60$$

where t_{fo} = time to flashover in room fire test, s
t_{ig} = time to ignition in cone calorimeter at 50 kW/m^2, s
A = total heat release during 5 minutes after ignition at 50 kW/m^2 (THR_{300}), J/m^2
ρ = density, kg/m^3

he equation is so far valid only for the room scenario studied with linings on both walls and ceiling. However, it can still serve as a simple tool for predictions of this scenario which is widely used and as n alternative to more advanced models. It might also be extended to other scenarios when more data ecome available.

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APPENDIX

Products tested.

EUREFIC products.

No.	Product	Thickness mm	Density kg/m^3	Surface weight g/m^2
1.	Painted gypsum paper plasterboard	12	800	100***
2.	Ordinary birch plywood	12	600	
3.	Textile wallcovering on gypsum paper plasterboard	12+1 *	800	505****
4.	Melamine-faced high density non-combustible board	12+1.5 *	1055**	
5.	Plastic-faced steel sheet on mineral wool	23+0.15+ +0.7 *	640**	
6.	FR particle board, type B1	16	630	
7.	Combustible-faced mineral wool	30+1 *	87**	37
8.	FR particle board	12	750	
9.	Plastic-faced steel sheet on polyurethane foam	80+0.1+ +1 *	160**	
10.	PVC-wallcarpet on gypsum paper plasterboard	12+0.9 *	800	1250****
11.	FR extruded polystyrene foam	25	37	

* Thickness of surface layer(s).

** Total.

*** Paint weight.

**** Base paper + surface covering.

Nordic round robin products.

No.	Product	Thickness mm	Density kg/m^3
12.	Birch plywood	12	600
13.	FR plywood	9	620
14.	Melamine-faced particle board	12+0.1 *	680
15.	FR polystyrene	25	30

* Thickness of surface layer.

Scandinavian products.

No.	Product	Thickness mm	Density kg/m^3
16.	Particle board	10	670
17.	Insulating wood fiber board	13	250
18.	Medium density wood fiber board	12	655
19.	Wood panel, spruce	11	450
20.	Melamine-faced particle board	12+1 *	870
21.	Plastic wallcovering on gypsum board	13+0.7 *	725
22.	Textile wallcovering on gypsum board	13+0.5 *	725
23.	Textile wallcovering on rockwool	42+0.5 *	150
24.	Paper wallcovering on particle board	10+0.5 *	670
25.	Rigid polyurethane foam	30	32
26.	Expanded polystyrene	49	18
27.	Paper wallcovering on gypsum board	13+0.5*	725
28.	Gypsum board	13	725

* Thickness of surface layer.

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