CAR FIRES WITH SPRINKLERS: A STUDY ON THE EUROCODE FOR SPRINKLERS

Mikko Partanen [a], Markku Heinisuo [a]

[a] Tampere University of Technology, Faculty of Business and Built Environment, Tampere, Finland

Abstract

The effect of sprinklers is taken into account in EN 1991-1-2 using reduction factors for the fire load. The applicability of the Eurocode method to car fires was studied by modelling the fires with Version 5.5.3 of the FDS program by NIST. The computer model is validated against tests completed in the UK in 2006-2009. Three medium-size car fires are modelled without and with the typical sprinklers used in car parks. The validation results showed that the developed car fire model works well with the actual reference fires, with and without sprinklers. The Eurocode reduction of fire load with sprinklers gives the same maximum temperatures as the simulation with sprinklers up to the first peak of the heat release rate (HRR). The Eurocode reduction does not take into account the fact that adjacent cars do not ignite, as is the case with the developed model and as observed in the tests. The Eurocode method is reliable up to the first peak, after that it is very conservative.

Keywords: car fire, sprinkler, Eurocode, FDS.

INTRODUCTION

Fire safety is one of the key issues when designing buildings. Car parks, open or enclosed, are typical in modern urban environments. Car fires have been studied for many years. The study of the of heat release rate (HRR) of cars began only with the car tests of VTT in Finland in 1991 (Mangs & Loikkanen, 1991). After that many researches have been completed (BRE, 2009). Extensive literature references and interesting statistical data are given in (Li, 2004). Not only cars, but also parts of cars, such as tyres (Gratkowski, 2012) and engine compartments (Weisenpacher et al, 2010) have also been studied. The /actual heat release rate as function of time from ignition is generally the main property in the modelling of fires.

Car fires have in many cases been modelled using computational fluid dynamics (CFD), and most of the analyses, such as (Halada et al, 2012), have been completed using a fire dynamics simulator (FDS) by NIST (Mc Grattan et al, 2010, or older version). Only CFD is considered in this study.

Regarding structural design in fire, the most advanced approach is to use the probabilistic method where the effects (mechanical loads, fire) and the resistances, including passive and active fire-fighting, are determined with their statistical values (distribution, mean, variation) up to the required safety index presented in the Eurocodes for accidental events for the design life time of the building. This method is used in (Schaumann et al, 2010) for open car parks. The Eurocodes allow using not only a fully probabilistic method but also the performance based method which uses the relevant HRR data of the fire to determine temperatures in fire. The Eurocode (EN 1991-1-2, 2003) includes reduction factors for fire loads when sprinklers are used. After the determination of the gas and structure temperatures, the resistances of structures can be checked during the entire fire. In most cases heat transfer analysis and mechanical analysis of structures can be done independently.

No design data for car fires are given in the Eurocodes. The main goal of this paper is to provide background data for car fires and to study the usability of the reduction factors for sprinklers mentioned in the Eurocodes. It is believed by the authors that car fires have generally been well studied and documented, starting with typical cars in the car parks of buildings (Schleich et al, 1997) and ending up with the worst case scenario involving petrol tankers (see Haack et al, 2005).

1 FDS MODEL AND ITS VALIDATION

1.1 The FDS model for car fires

The developed model for category 2 (Schleich et al, 1997) car fires includes a burning plane of 1.8x4.8 m^2 (Schleich, 2010) located 500 mm above the floor level. The heat release rate (HRR) curve is fitted to (Schleich et al, 1997) with a peak value of 8 MW at 25 minutes from ignition. The design curve is fitted so that the released energy per one car is 7500 MJ, as required by the categorisation. The adjacent cars are located at a distance of 600 mm, and the next car ignites 12 minutes after the previous one (Joyeux et al, 2001). To make it possible for the fire to spread from one car to another, the burning plane is assigned material properties representing the inner parts of the car. The details of the modelling are given in (Heinisuo & Partanen, 2013). Tyres are objects with an independent HRR curve based on (Gratkowski, 2012). Generally the ignition temperature of tyres is 371-425 ^{o}C (Gratkowski, 2012) but in this study it is set to 250 ^{o}C to make the overall car model work better with the verification tests. Thus, two car fire models were developed. In one model the ignition time of the adjacent car was pre-set to 12 minutes. The second model was fine-tuned to make the second car ignite about 12 minutes after the first one via broken windows and burning tyres. The second model can also be used for other purposes than adjacent car fires, for example, if the ignition source is some other nearby object.

The windows were supposed to break at 300 ^{o}C (Weisenpacher et al, 2012). The side windows of the first ignited car are open to have enough oxygen to enable the fire to burn inside the car. The fire spreads via breaking windows and burning tyres from one car to another so that the second car ignites about 720 s (12 minutes) after the first one, and the third car ignites about 1440 s (24 minutes) after the first. Two materials are used for windows. Automotive windscreens are usually made of laminated glass while side and rear windows are of tempered glass. The car itself is modelled using the non-burning wrought aluminium (Bertram & Buxmann, 2007), used in cars today. There are ventilation openings at the front of the cars and around the tyres. Two tyres have thermocouples monitoring the spread of the fire from one car to another. There are also thermocouples at each burning plane to monitor the ignition temperatures inside the car.

The grid size is 100x100x100 mm^3 near the car making the resolution (Heinisuo et al, 2008) 25, which means a rather dense and accurate grid. Some analyses use a grid size of 200x200x200 mm^3 to accelerate computations at the 3 m zone from the edges of the computational space.

The HRR curves for one and three adjacent cars are shown in Figs. 1 and 2.

1

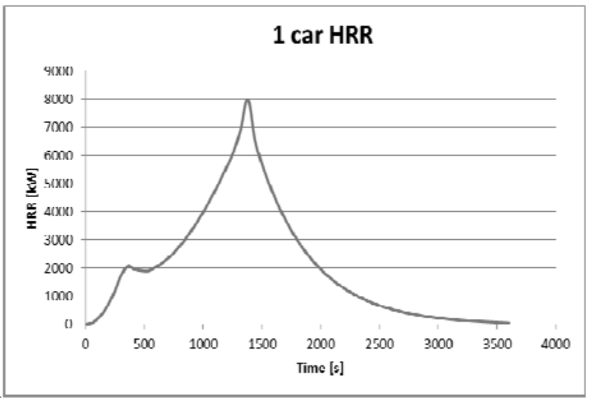


Fig. 1 HRR for one car

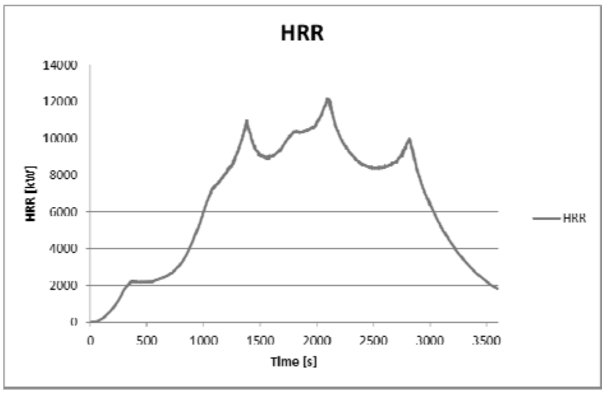
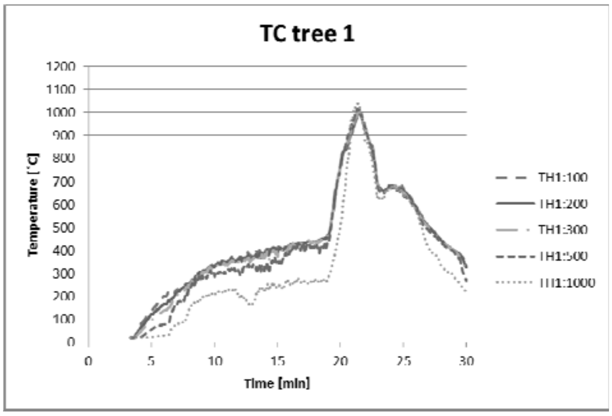


Fig. 2 HRR for three adjacent cars

1.2 Validation of the developed model

The FDS car fire model was validated with full scale tests (BRE, 2009). In the first test three cars, a Renault Laguna (car 1), a Renault Clio (car 2) and a Ford Mondeo Estate (car 3) were burned in the absence of sprinklers. They were modelled as category 2 cars, as described above. The computational space was fitted to the tests using initial data describing the test environment. The FDS model is shown in Fig. 3.



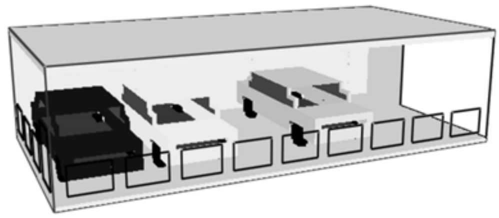


Fig. 3 FDS model of test (car 1 left, etc)

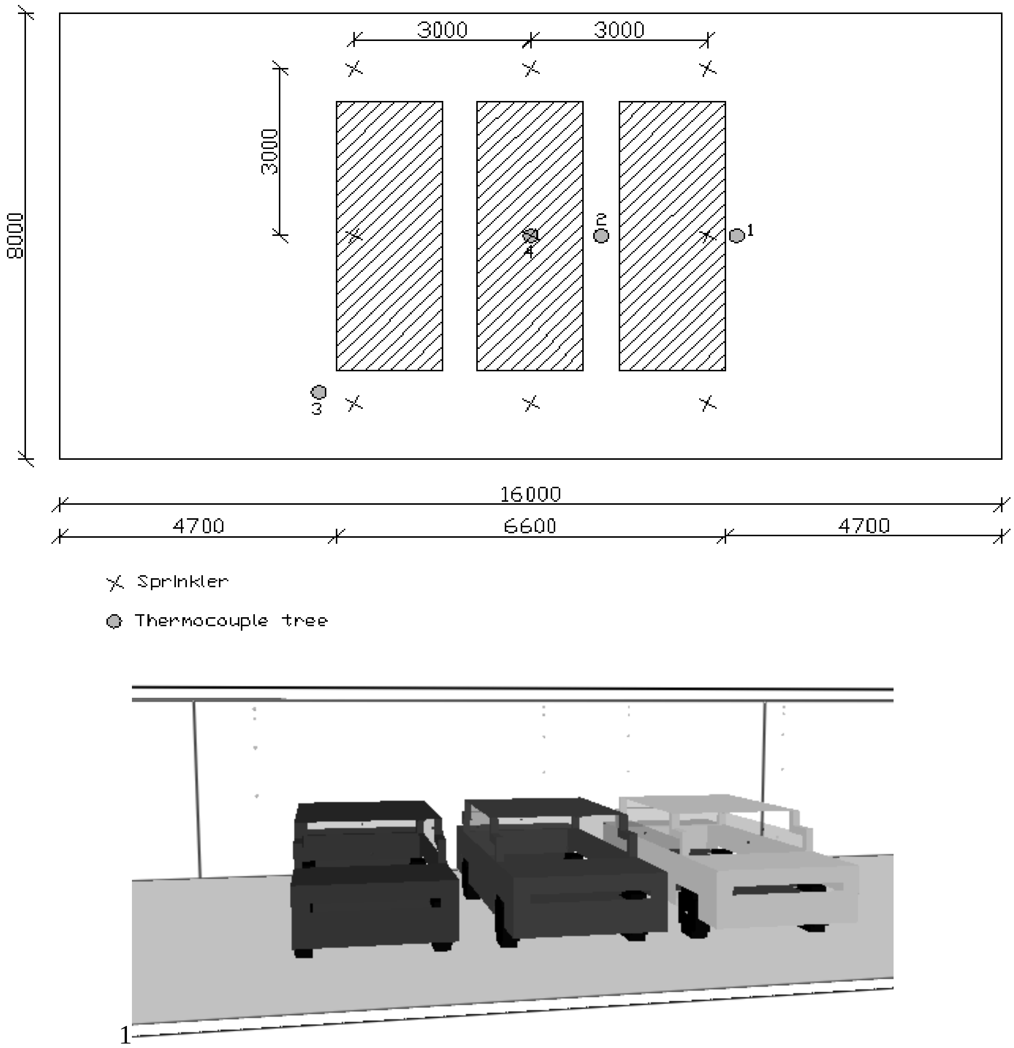
Fig. 4 Temperatures of the model

The fire started at car 1 and continued for about one hour. Temperatures were recorded in the model at thermocouple trees, as in the tests. Fig. 4 illustrates the temperatures in one tree where thermocouples were located 100, 200, 300, 500 and 1000 mm below the ceiling. The temperatures in all recorded thermocouples of the model were about the same as in the test.

In the second test three cars, a Renault Grand Escape, a Seat Ibiza and a Land Rover Freelancer were burned in the presence of sprinklers. These cars were modelled as category 2 cars, as above. The test environment with sprinklers was modelled, too. Six sprinklers of the test had an OH2 classification, 5 mm/min and 12 m^2 per head. In the BRE test only one car ignited, as was the case with the simulation model. The temperatures based on the model were higher in two thermocouple trees and smaller in one tree than in the tests. This is due the fact that the first and only car that burned in the test was a Renault Grand Escape, not a category 2 car as in the simulation. The Renault Grand Escape is a category 5 car that releases 12000 MJ of energy in fire. Category 2 cars, on the other hand, release 7500 MJ.

2 CASE STUDY WITH THREE ADJACENT CARS

The virtual car park with a floor area of 8x16 m^2 and a free height of 3 m was modelled with three category 2 cars in the middle. There were no walls in the computational space. The floor and roof were modelled as 100 mm thick non-burning concrete. Four thermocouple trees and nine similar sprinklers as in the BRE test were used in the model, as shown in Fig. 5. The flow rates of the sprinklers in this case were 45 l/min, not 60 l/min as in the BRE test, because the sprinkler coverage area per head was now 9m^2. Thus, the requirement for sprinkler water flow rate per unit floor area of 5 mm/minute for car parks was fulfilled.



1

Fig. 5 Virtual car park case

This case was modelled without and with sprinklers. Then, the HRR curve was reduced imitating Eurocodes: The automatic water extinguishing system reduces the design fire load by a factor of 0.61. In the FDS model this reduction was completed by reducing the given HRRPUA value of the burning plane inside the car by a factor of 0.69. Numerical integration was used to calculate the released energy, which with this value was 0.61 times the original energy, referred to as EC0.61. The same technique was used in two other simulations referred to as EC0.43 and EC0.53. The HRR curves for the simulated cases are shown in Fig. 6.

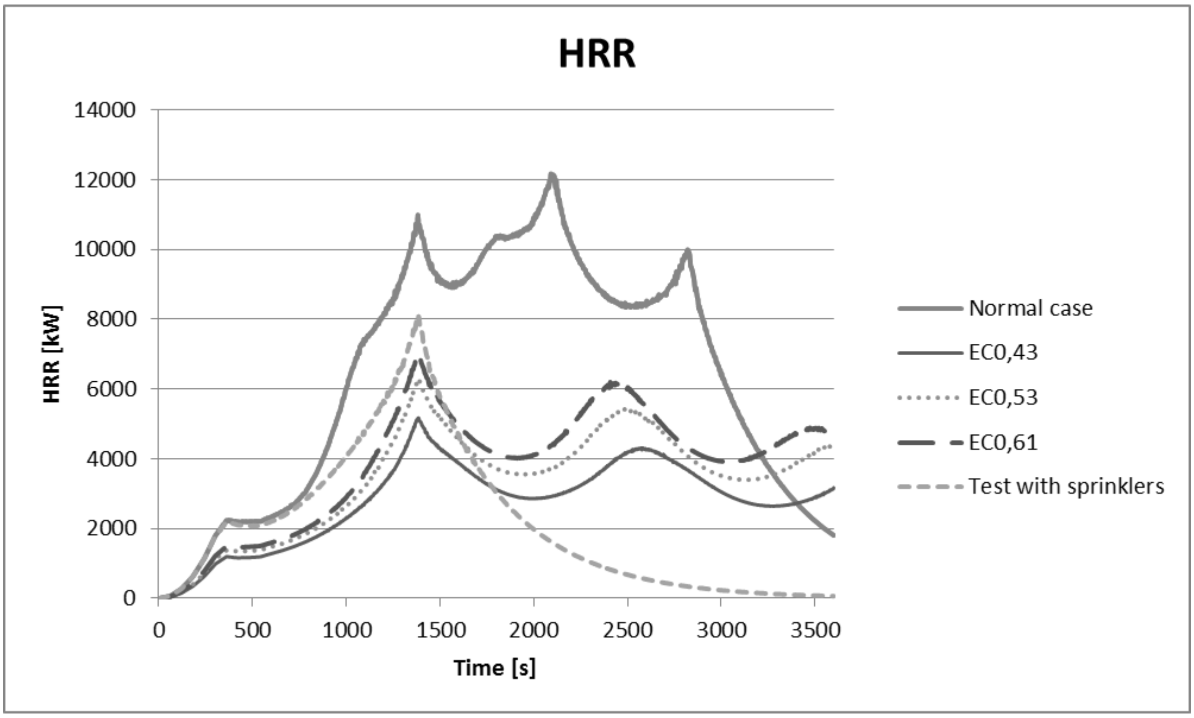


Fig. 6 Virtual car park case

It can be seen that the Eurocode reduction does not take into account the fact that adjacent cars do not ignite, as is the case with the developed model and as observed in the tests. Typical temperatures in the virtual thermocouple trees are shown in Fig. 7.

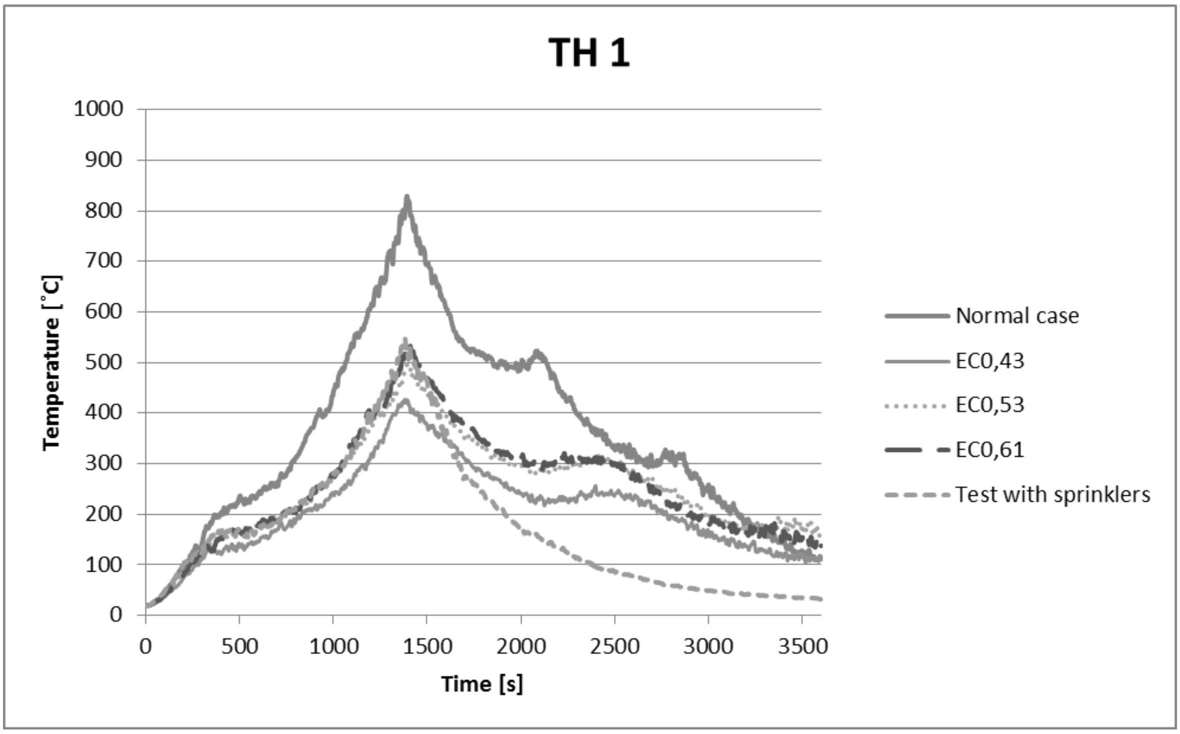


Fig. 7 Temperatures according to simulations

It can be seen that the Eurocode-based reduction of fire load in the presence of sprinklers (see Fig. 7, EC0,61) results in the same maximum temperatures as the simulation with sprinklers at the first peak of HRR. The Eurocode method is reliable for design within this range if the maximum temperatures at the beginning of the fire are those used in the fire design of structures. If it is used to simulate temperatures after the first peak of HRR, the temperatures are very conservative based on these results.

REFERENCES

Bertram, M., Buxmann, K., etc., Improving Sustainability in the Transport Sector Through Weight Reduction and the Application of Aluminium, International Aluminium Institute (IAI), 2007, 55 pages

BRE, Martin M., Fire Spread in Car Parks, Final Research Report BD 2552 (D14 V1)231-569, 16.2.2009, 116 pages

EN 1991-1-2, Eurocode 1: Actions on structures, Part 1-2: General actions, Actions on structures exposed to fire, CEN, Bryssels, 2003.

Gratkowski, M.T., Burning Characteristics of Automotive Tires, Fire Technology, United States Department of Justice, Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF), Fire Research Laboratory (FRL), DOI: 10.1007/s10694-012-0274-9, 2012

Haack et.al., Technical Report – Part 1. Design Fire Scenarios, Thematic Network, FIT – Fire in Tunnels, The Fifth Framework Programme of the European Community 'Competitive and Sustainable Growth'. Contract no G1RT-CT-2001-05017, 2005.

Halada, L., Weisenpacher, P., Glasa, J., Computer Modelling of Automobile Fires, Advances in Modeling of Fluid Dynamics, Dr. Chaoqun Liu (Ed.), ISBN: 978-953-51-0834-4, InTech, DOI: 10.5772/48600, 2012.

Heinisuo, M., Laasonen, M., Hyvärinen, T., Berg, T., Product modeling in fire safety concept, effect of grid sizes and obstacles to steel temperatures, IABSE Helsinki 2008 Congress, 2008.

Heinisuo, M., Partanen, M., Modeling of Car Fires with Sprinklers, Research Report, Tampere University of Technology, Faculty of Business and Built Environment, Tampere, 2013.

Joyeux, D., Kruppa, J. Cajot, L.G. Schleich, J.B. Van de Leur, P. Twilt, L. Demonstration of real fire tests in car parks and high buildings (2001), European Research Contract n° 7215 PP 025, Final report.

Li, Y., Assessment of Vehicle Fires in New Zealand Parking Buildings, MEFE Thesis, University of Canterbury, Christchurch, New Zealand, 2004.

Mangs, J., Loikkanen, P., Fire tests in passenger cars, VTT Research Report No.TSPAL00455/90, VTT Espoo, Finland, 1991.

Mc Grattan, K., et al., Fire Dynamics Simulator, Technical reference guide. National Institute of Standards and Technology, version 5.5, 2010, USA

Schaumann, P., Sothmann, J., Albrecht, C. Safety concept for structural fire design – application and validation in steel and composite construction, Proceedings of 11th International Seminar of Fire Protection , June 2010, Leipzig, 2010

Schleich, J.B., Cajot, L.G., Franssen, J.M., Kruppa, J., Joyeux, D., Twilt, L., Van Oerle, J., Aurtenetxe, G. Development of design rules for steel structures subjected to natural fires in closed car parks (1997), EUR 18867EN, Report.

Shleich, J.B, Modern Fire Engineering, Fire Design of Car Parks, Arcelor Profil, Luxembourg Research Centre. (Internet publication), 2010.

Weisenpacher, P., Glasa, J., Halada, L., Computer simulation of automobile engine compartment fire. Proc. of the Int. Congress on Combustion and Fire Dynamics (J. A. Capote, ed.). Santander: GIDAI - Fire Safety - Research and Technology, 2010, p. 257-270. ISBN 978-84-86116-23-1

Weisenpacher, P., Glasa, J. and Halada, L., Parallel simulation of automobile interior fire and its spread onto other vehicles, Fire Computer Modeling: international congress, [Santander, 19 de 2012]/ edited by Jorge A Capote, Daniel Alvear, ISBN 978-84-86116-69-9, 2012, pp. 329-338, 2012.