IRF'2009, Porto 20-24 July 2009

Faculty of Engineering, University of Porto

INTEGRITY RELIABILITY AND FAILURE

CHALLENGES AND OPPORTUNITIES

Editors:

J.F. Silva Gomes

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Published by

INEGI-Instituto de Engenharia Mecânica e Gestão Industrial
Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
Tel:+351 22 957 87 10; Email: inegi@inegi.up.pt
www.inegi.up.pt

July, 2009

ISBN: 978-972-8826-22-2
Legal D.N: 295639/09

Printed by:

LusoImpress (Grupo Claret)
Rua Venceslau Ramos, s/n – 4430-929 Avintes, Portugal
Tel:+351 22 787 73 20; Fax:+351 22 787 73 29

IRF'2009

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Edições INEGI
(2009)

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CHAPTER XVIII

SYMPOSIUM

STRUCTURAL SAFETY

Coordinated by

Paulo A.G. Piloto[1(*)] and Alberto Meda[2(*)]

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In Association with

IRF'2009

3rd International Conference on Integrity, Reliability and Failure

Porto, Portugal

20-24 July 2009

Editors

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Introduction to Symposium on Structural Safety

Safe design is a design process that eliminates hazards, or minimizes potential risks, by involving decision makers and considering the life cycle of structures and materials. Safe design approach will generate a well-informed design option that should eliminate these potential problems to those who makes the product and to those who use it.

Structural safety in design will cover the design aspects of safe structures and components, using different materials. Advances in standards and regulations should permanently ensure safety with the best practices and methods. Advanced analysis methods should be permanently improved and used to prevent such potential risk in structures and materials. Designers should guarantee structural integrity and reliability.

The following communications will present different aspects in Damage Analysis and Assessment, Fire Safety Engineering, Life Cycle Analysis, Natural and Man-Made Hazards, Performance-Based Design Methods, Prescribed Design Methods, Computational Methods and Simplified Methods for Structural Safety.

Paulo Piloto
Instituto Politécnico de Bragança
Alberto Meda
University of Rome "Tor Vergata"

REF: S2003_A0471

EFFICIENCY EVALUATION OF INTUMESCENT COATINGS USED FOR FIRE PROTECTION: COMPARISON BETWEEN NUMERICAL METHOD AND EXPERIMENTAL RESULTS

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SYNOPSIS

An experimental study to assess the performance of water-based intumescent paints, used as a passive fire protection material, is presented. The specimens are steel plates coated with two different paints, three dry film thicknesses and tested with two different radiant heat fluxes in a cone calorimeter. The efficiency of this protection is attained regarding the substrate temperature evolution. A comparison between these experimental results and the ones obtained from a numerical model is presented. The numerical model considers the coating decomposition, and models the protection by two layers, the reacted and the unreacted layer (Mesquita et al, 2009).

INTRODUCTION

Thin film intumescent coatings are mostly used in the civil construction industry to increase the fire resistance requirements prescribed by the structural fire design codes. They are applied essentially to structural elements with inadequate fire behaviour, like the case of steel and aluminium structures. An intumescent coating when submitted to fire starts to bubble and swells to form a carbonaceous, porous, low-density char, reducing the heat transfer to underlying virgin material layer and therefore to the substrate.

This work presents an experimental study to assess the performance of water-based intumescent paints used as a passive fire protection material. These tests were performed in a cone calorimeter (ISO, 2002), in squared steel plates, with 4 and 6 [mm] thick, coated with two different paints (A and B), three dry film thicknesses (0.5, 1.5 and 2.5 [mm]) and considering two different radiant heat fluxes (35 and 75 [kWm^{-2}]). Temperatures are measured by means of four thermocouples, type k, welded at the plate in the heating side and at the opposite side, at two different positions. Between the steel plate and the sample older two silicate plates were used to put the specimen in place and also a thermocouple was introduced inside to measure their temperature variation. During tests, among other quantities, steel temperature, intumescence mass loss and thickness variation were measured.

A numerical model is also presented to study the intumescence behaviour. The paint thermal decomposition numerical model is based on the Arrhenius equation, to simulate the chemical reaction decomposition. The moving boundary and the free boundary locations, the depth of the carbonaceous and virgin coating layers (L(t), s(t)) are determined as part of the problem. The energy equation for the overall conservation of energy within the intumescence zone can be obtained by combining the energy equation for the gases with that of the solid char material.

The solution method was implemented in a Matlab routine using the Method Of Lines (MOL) (Wouwer, 2004), and the integrator *ode15s* to solve the set of ordinary differential equations.

The temperature field is determined by the steel and virgin energy equations. When the front reaches the pyrolysis temperature, equal to 250 [ºc], starts to decompose and to move. Then the moving front rate is determined and the intumescence starts. The position of the free boundary is set equal to the experimental results and the intumescence temperature field is determined. In each time step the virgin and char layers are remeshed.

RESULTS

Measured values from the thermocouples welded on the bottom of the plate are very close to the temperatures at the top, as presented in Fig. 1. The numerical results follow reasonably well the experimental values, as presented in Fig. 2. The results show that both the determined steel temperatures and the moving front are strongly dependent on the activation energy that defines the amount of mass loss of virgin paint.

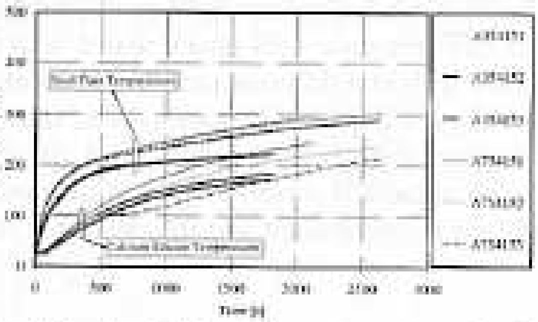

Fig. 1 Steel and calcium silicate temperatures for 4 [mm] specimens coated with a DFT of coating A equal to 1.5 [mm], tested with heat fluxes of 35 and 75 [kWm^{-2}].

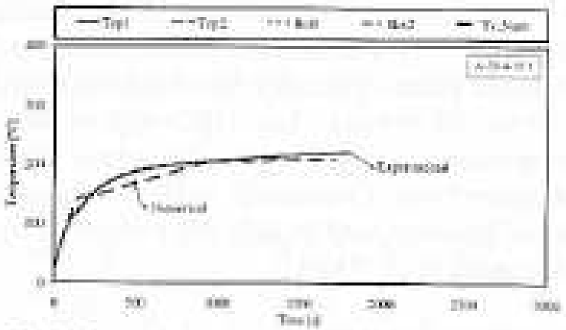

Fig. 2 Comparison of measured and computed steel temperatures, $E_0 = 125 KJmol^{-1}$.

CONCLUSIONS

This paper has presented a set of experimental tests conducted in a cone calorimeter to assess the intumescent coating behaviour when used in fire protection. The intumescence depends on the initial dry thickness and on the incident heat flux. A numerical model is applied to determine the steel temperature considering the intumescence measured in the experimental tests. The results show that temperature variation is strongly dependent on the activation energy.

REFERENCES

[1] ISO 5660-1:2002, Reaction-to-fire tests - Heat release, smoke production and mass loss rate. Part 1: Heat release rate (cone calorimeter method), International Organization for Standardization, 2002.

[2] Mesquita, L.M.R.; Piloto, P.A.G.; Vaz, M.A.P.; Pinto, T.; "Decomposition of intumescent coatings: comparison between numerical method and experimental results", Application of Structural Fire Design, ISBN: 978-80-01-04266-3, pp. 140-145, Prague, Czech Republic, 19-20 February 2009.

[3] Wouwer A.V, Saucez P., and W. E. Schiesser, "Simulation of Distributed Parameter Systems Using a Matlab- Based Method of Lines Toolbox: Chemical Engineering Applications", Ind. Eng. Chem. Res. 2004, 43, 3469-3477.

About the Book

As the engineering community continues to cross the boundaries of known practices, materials and manufacturing techniques into the frontiers of new functional materials, environments and applications, the opportunities for catastrophic failures will inevitably increase. If our knowledge of how to engineer systems, structures and components to minimize or prevent catastrophic failure is to keep pace with modern manufacturing technologies, the demanding applications, and the intolerance of a safety conscious society, we must continue our efforts to develop and use superior materials, apply reliable analytical techniques and validate these with sound experimental tools.

This book contains the Abstracts of papers presented at the 3rd International Conference on Integrity, Reliability and Failure, held at the Faculty of Engineering, University of Porto, Portugal, 20-24 July 2009. This is part of a prestigious series of Integrity Reliability and Failure conferences coordinated by the International Scientific Committee on Mechanics and Materials in Design. The conference attracted over 250 participants with 310 accepted academic and industrial submissions from 45 different countries around the world. These papers were presented in July 2024, 2009 in the ma gnificent city of Porto, Portugal, and the conference themes focused on design, nanotechnology, advanced materials, computational and structural mechanics, experimental mechanics, structural safety, energetic systems, and case studies.

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