Institution: University of Ulster

Unit of Assessment: 16 Architecture, Built Environment and Planning

Title of case study: Designing Novel Fire Safe Materials: FIRESAFE

1. Summary of the impact (indicative maximum 100 words)

The use of fire retardants is a requirement to reduce fire severity and deaths but is also controversial due to environmental (leaching) and health consequences of commonly used halogenated fire retardants. A novel methodology has been developed and validated in the Fire Safety Engineering Research and Technology centre (FireSERT), Built Environment Research Institute, for the prediction of large-scale burning behaviour of fire retarded polymers by combining small-scale (mg size) experiments with computer simulations of fire growth and toxicity. The research has been instrumental for companies in redesigning their products (fire doors and intumescent coatings) and is informing the development of EU regulations regarding the use and replacement of halogenated fire retardants. The research output has been published in leading journals, cited widely internationally and referenced by key organisations.

2. Underpinning research (indicative maximum 500 words)

The underpinning research at Ulster on advanced fire safe materials (FIRESAFE) is based on determining key flammability properties from small-scale tests (reference 3.1) and using these in computer models for fire growth and toxicity prediction. This has enabled the design, development and evaluation of fire safe materials through the selection of appropriate fire retardants (reactive or additive) including nanoparticles at a stage prior to the use of such formulations in large-scale manufacturing production which may require extensive retooling at significant cost.

The fire dynamics and materials research group in FireSERT, where the FIRESAFE research has been advanced, is led by Prof Delichatsios (in post since 2002) and includes Dr Zhang (lecturer since 2008) and a number of members of research staff Dr Bakirtzis (2006-2010 and 2012-2013), Dr Ramani (2010-2013), Dr Suzanne (2010-2012) and Dr Ukleja (2009-2013). The scientific output of this research is exemplified by the selected references in Section 3.

The research has been supported by grants from EPSRC (grant 3a - *Flames on building facades*) and European FP6 and FP7 awards (on material fire resistance and fire modelling). In the FP6 PredFIRE-NANO project (grant 3b - *Predicting Fire Behaviour of Nanocomposites from Intrinsic Properties*, coordinated by Delichatsios), polymers modified with fire retardants and nanoclays were analysed. Small-scale degradation and toxicity tests (mg samples) were initially performed, from which key intrinsic properties of materials were deduced (reference 3.2 and 3.3). These properties can then be incorporated into a numerical model to predict ignition and pyrolysis behaviours in a cone calorimeter. The new methodology developed was validated for a nylon nanocomposite (reference 3.4) and, subsequently, successfully applied to other polymer nanocomposites (reference 3.5). Further validation of the methodology used flaxboard with intumescent coatings with/without nanoclays. The methodology was also incorporated in a computational fluid dynamics (CFD) model and validated against experimental data, for which large-scale tests were also conducted (reference 3.6).

In September 2009, the research group was awarded a FP7 European project, ENFIRO (grant 3c - *Life Cycle Assessment of Environment-Compatible Flame Retardants,* Delichatsios and Zhang), as part of a consortium including the University of Amsterdam, Stockholm University and Utrecht University. This project examined alternative fire retardants (halogen-free fire retardants, HFFRs) to replace brominated fire retardants (BFRs), in terms of their impact on environmental and toxicological risks, viability of industrial implementation, production of fire retardants and fire safety. The research focussed on flammability testing of HFFRs and BFRs and comparison of their respective performance as characterised by three parameters: flame spread, smoke yield and efficiency of combustion. The results show that phosphorus-based retardants combined with nanoclays can achieve better or similar fire performance as BFRs, while producing significantly less toxic gases.

In 2011, the group was awarded a further FP7 project on the flammability on new light composite materials on new generation aircrafts (grant 3d - AircraftFire, *Fire risks assessment and increase of passenger survivability*). The project assesses the fire resistance and fire behaviour of lightweight carbon fibre reinforced composite materials used to replace the aluminium skin for the fuselage of aircraft based on the methodology developed at FireSERT on fire safe composite materials.

In summary, our approach in designing fire safe materials consists of two parts namely inserting additives inside the material whether a polymer or a building material (concrete) and, in addition, applying intumescent paint on the surface of the final product. The additive to the material (polymer, concrete) can be chemical (such as polyphosphates), nanoparticles (such as vermiculite), fibres (steel, carbon-X) or two dimensional sheets (such as graphene). These additives provide additional advantages for the materials and contribute significantly to their impact (Section 4). Further development of these designs has led to the award of two new projects in 2013, one through European FP7 funding (*Energy Efficient Lightweight-Sustainable-Safe-Steel Construction)* and the other funded by the National Fire Protection Association of America (NFPA) in collaboration with Commonwealth Scientific Industrial Research Organisation of Australia (CSIRO) (*Fire Hazards of Combustible Exterior Walls*) enabling the future sustainability of the underpinning research.

3. References to the research (indicative maximum of six references)

The underpinning research has been published in leading fire and combustion journals, the status of which is evidenced by high impact factors for the subject area.

3.1 Delichatsios, M, Paroz, B and Bhargava, A (2003) Flammability properties for charring materials, *Fire Safety Journal*, 38 (3), pp. 219-228. 10.1016/S0379-7112(02)00080-2

3.2 Ramani, A, Hagen, M, Hereid, J, Zhang, J and Delichatsios, M (2010) Interaction of a phosphorus-based FR, a nanoclay and PA6. Part 2 interaction of the complete PA6 polymer nanocomposites, *Fire and Materials*, 34 (2), pp. 77-93. 10.1002/fam.1012

3.3 Zhang, J, Hereid, J, Hagen, M, Bakirtzis, D, Delichatsios, MA, Fina, A, Castrovinci, A, Camino, G, Samyn, F and Bourbigot, S (2009) Effects of nanoclay and fire retardants on fire retardancy of a polymer blend of EVA and LDPE, *Fire Safety Journal*, 44 (4), pp. 504-513. 10.1016/j.firesaf.2008.10.005

3.4 Zhang, J, Delichatsios, MA and Bourbigot, S (2009) Experimental and numerical study of the effects of nanoparticles on pyrolysis of a polyamide 6 (PA6) nanocomposite in the cone calorimeter, *Combustion and Flame*, 156 (11), pp. 2056-2062. 10.1016/j.combustflame.2009.08.002

3.5 Zhang, J and Delichatsios, M (2010) Further validation of a numerical model for prediction of pyrolysis of polymer nanocomposites in the cone calorimeter, *Fire Technology*, 46, pp. 307-319. 10.1007/s10694-008-0073-5

3.6 Zhang, J, Delichatsios, MA, McKee, M, and Ukleja, S (2012) Experimental and numerical study of burning behaviours of flaxboard with intumescent coating and nanoparticles in the cone calorimeter and single burning item tests, *Fire and Materials*, 36, pp. 554-564. 10.1002/fam.1114

The quality of the underpinning research is also evidenced by the awarding of four EPSRC/European projects

3a Delichatsios
Flames on building facades
EPSRC
01/05/2006 – 30/04/2010
£176,046

3b Delichatsios
Predicting Fire Behaviour of Nanocomposites from Intrinsic Properties: PredFire-Nano
CEC FP6 NMP STREP
01/02/2005 – 31/12/2008
£567,906
3c Delichatsios and Zhang
Enfiro: Life Cycle Assessment of Environment-Compatible Flame Retardants
CEC FP7 - Environment
01/09/2009 to 31/11/2012
£333,887
3d Delichatsios and Zhang
AircraftFire: Fire risks assessment and increase of passenger survivability
CEC FP7
01/01/2011 to 31/12/202013
£288,302

4. Details of the impact (indicative maximum 750 words)

The impact of the underpinning research concerns technology transfer to companies mainly in the SME sector, with *reach* apparent in terms of both the diversity of manufacturing companies and their geographical location (Ireland, UK and Europe). *Significance* is through improving the quality of products and sales, as well as the establishment of scientifically based assessment for the substitution of halogenated fire retardants by environmentally compatible fire retardants.

Technology transfer of our methodology to modify, predict and model fire performance has been utilised extensively by industry. Applications include the development of new high performance fabrics, high fire resistance wall or floor insulation, manufacturing of new fire doors and improved intumescent coatings. The *significance* of the research lies in the impact on production systems in these areas and ultimately, has been incorporated into products used in a range of circumstances embracing both domestic and commercial environments. Thus the *reach* of the impact whilst initially with specific companies has, through incorporation into products, been extended to other applications.

Examples of manufacturing companies employing the underpinning research are SITEX (high performance fabrics), Pollock Lifts (designers of lifts for disabled people) and Essexford Joinery (redevelopment of doors and core materials for doors). New designs implemented by these companies are based on FireSERT's research with benefit apparent in reducing weight, whilst at the same time increasing the fire resistance of fabrics (SITEX), floor partitions (Pollock Lifts) and fire doors (Essexford).

Research in FireSERT on flame resistant fabrics for industrial and fire-fighting protective clothing provides an alternative to the traditional meta-aramid fabrics (Dupont Kevlar). Application of these fabrics by SITEX (corroborating statement 1, source 5.1) has produced a number of benefits in relation to fabric/fibre blends. Fire barrier research on materials in FireSERT has permitted the assessment of performance levels needed for fabric systems. This has *significance* in establishing new coating technology that is environmentally safe and boosts performance. Specifically this has enabled SITEX to produce fabrics offering a high level of fire protection without using finishes or processes which are chemically negative with significant environmental gain. Wider societal benefit is the reduction in the level of toxic gas in the event of fire (source 5.2). Furthermore, the new protective fabrics are competitive in price and quality relative to existing meta-aramid alternatives.

Further evidence of the industrial *significance* of materials research at FireSERT is the application by Pollok Lifts (corroborating statement 2, source 5.3) which, as a manufacturing and service based company in the SME sector, has utilised FireSERT's research on the use of nano-particles, environmentally safe fire retardants and intumescent paints in the improvement and development of their 20 Series Homelift (Through Floor Lift). These fire retardants were used to improve the fire resistance of floor partitions and have enabled Pollock Lifts to meet and exceed the requirements of specific clauses in BS 5900:2012 namely “Fire protection” and “Behaviour of homelift in the event of fire”. Use of FireSERT research has facilitated the company (Pollock Lifts) in the development of a market leading, cost effective product with a *reach* that extends into different market sectors namely shops, offices, hospitals and residential properties.

In the case of Essexford Joinery (corroborating statement 3, source 5.4) a similar procedure was followed transferring FireSERT’s research for the design of new doors, through implementation and testing the application of new intumescent coatings. The *significance* of these developments is an increase in the fire resistance of doors produced by Essexford which has resulted in an increase in manufacturing output and a product *reach* across economic sectors (source 5.5). These benefits, as illustrated by the experience of such companies, have resulted in superior products and an increase in sales as an outcome of applying the research developed by FireSERT.

The methodologies underpinning the research have been applied by companies beyond the UK and Ireland. As an example, IRIS Vernici (corroborating statement 4, source 5.6), an Italian based SME specialising in production of coatings for the building and manufacturing industry, has used FireSERT’s research in improving the fire resistance of intumescent coatings by the inclusion of nanoclays. The underpinning research has played an important role in the development of several commercial intumescent coatings (CHAR 17, CHAR 21 and CHAR 22) and, more recently, of the unsaturated polyester intumescent system. *Significance* is in terms of reducing the weight of components in buildings (for example plasterboard), which facilitates the construction and rehabilitation of buildings and offers less expensive options. The use of environmentally safe fire retardants has assisted IRIS Vernici in surpassing regulation requirements and increasing their sales.

Flammability research undertaken as part of the ENFIRO project has contributed to the development of a complete Life Cycle Analysis (LCA) for regulating the replacement of currently used fire retardants (so called brominated) with environmentally friendly fire retardants. The environmental and toxicological hazards of brominated flame retardants (BFRs) means that a number of these BFRs have already been phased out with ecological benefit to society. Economic benefit from the change to environmentally-friendly fire retardants is substantial with forecasts predicting a global market for fire retardants of US$6 billion by 2018. In this respect, the *significance* of flammability research at FireSERT has been to demonstrate cost effectiveness and safety issues regarding the use of HFFRs to replace BFRs in products including application in the cable and electronic industry. The *reach* of FireSERT’s research on fire retardants has also impacted on product development by multi-national companies, for example CLARIANT has utilised the research at Ulster in the manufacturing and marketing of HFFRs (corroborating statement 5, source 5.7).

In summary, the research undertaken at FireSERT on fire safe materials is having significant industrial impact in terms of product development. The properties of these materials (lightweight, high strength, excellent fire resistance) are fundamental to their *significance* to industry and have a *reach* that is cross-sector in nature with benefit to society through enhanced fire protection.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Electronic copies of all sources including web links can be provided.

5.1 Corroborating statement 1 - Company owner, SITEX Protective Fabrics
5.2 SITEX web-link http://www.sitex.eu.com/
5.3 Corroborating statement 2 - Managing Director, Pollock Lifts
5.4 Corroborating statement 3 – General Manager, Essexford Joinery
5.5 Essexford web-link http://www.essexfordjoinery.ie/html/about.asp
5.6 Corroborating statement 4 – CEO, IRIS Vernici SRL
5.7 Corroborating statement 5 – Head of R&D Flame Retardants, CLARIANT.