Institution: University of Bolton
Unit of Assessment: 15 - General Engineering
Title of case study: Flame Retardant Technical Polypropylene Furnishing Fabrics
1. Summary of the impact (indicative maximum 100 words)

This case study is about the development of flame retardant (FR) polypropylene yarns used in upholstery fabrics for domestic and office furniture, automotive and floor coverings that will have predictable and reproducible fire retardant properties when subjected to standard testing procedures. Through the UK DTI funded project FLAMTECH (2002-2005) shared by Camira Fabrics Ltd., and the university, a range of novel polypropylene yarns having higher levels of consistent fire performance than the previously existing products in the market place were developed. A testing protocol which could establish individual fibre/yarn/fabric structural-fire property relationships and correlate these with (and hence predict) final fabric performance was also established. The project overlapped a concurrent EPSRC funded research in which nanocomposite fibres (including polypropylene) with improved flame retardancy and reduced melt dripping were developed. Camira were also members of the consortium managing this project. The major commercial outcome from these projects since 2005 is a flame retardant polypropylene product being marketed by Camira fabrics within their Perfentex brand and others are also being considered. This work also inspired the Production Director of Camira Fabrics to register at Bolton as a PhD-by-publication candidate and hence gain more knowledge about the subject area, as evidenced by the publication of her research papers (see Paper 1, Section 3).

2. Underpinning research (indicative maximum 500 words)

Synthetic fibres and in particular polypropylene (PP) are sometimes more flammable than their natural counterparts and unlike them, shrink and melt (often yielding flaming melt drips). They are, therefore, difficult to fire retard, thus presenting a major challenge in end-uses like contract furnishings where their superior tensile and abrasion properties are essential features. In an EPSRC studentship (2001 – 2004*,* supervised by Horrocks and Kandola*)* the potential of nanocomposite formation for developing flame retardancy in thermoplastic fibre-forming polymers was explored and this work lay the foundations for that described in this Case Study.

The DTI funded project FLAMTECH (2002-2005), comprised two strands:

(i) *Development FR technical PP yarns having optimized and superior performance.*

(ii) *Development of oxygen index flammability testing protocols for yarns and derived fabrics and define their interrelationship*

Strand (i) investigated novel fire retardant formulations including the inclusion of nanodispersed clays and Strand (ii) comprised a full analysis of the then (2002) current range of Camira PP fabrics with the aim of using modified oxygen index methodology to relate all fibre and fabric variables with standard flammability test results. The so-called French “M test”, NFP 92501-7, is used to assess fabric flammability behaviour in which fabrics are ignited under a radiant heat flux and must demonstrate minimum burn lengths and maximum extinction times to be acceptable for European contract furnishing fabric markets and it was evident that the then Camira PP fabric range was not able to consistently achieve the required “MI rating Pass” levels. Prof Horrocks was the PI and Dr (Prof now) Kandola worked as a researcher on this project. Industrial partners included Interface Fabrics (now Camira Fabrics) and McCleery Yarns, Northern Ireland and GGI Furniture UK. During the project, McCleery yarns were bought by Camira which enabled the latter company to be in full control of the production and quality of their polypropylene yarn supply. This and the results of the project had a significant effect in Camira’s ability to improve the overall flammability performance of its Perfentex fabric range.

With regard to Strand (i), a range of polypropylene samples containing nanoclays and non-brominated / brominated flame retardants were prepared and tested for flammability using LOI measurements and thermogravimetric analysis. The results showed that one flame retardant chemical only is not capable of effectively reducing the flammability of polypropylene while maintaining other acceptable fibre properties. However, it was evident that use of synergistic flame retardant moieties can be effective at levels < 5wt-%. The results also emphasised the importance of maximising dispersion of both clay and flame retardant, a factor which became evident during Strand (ii). While this research offered a more fundamental study of the challenges of flame retarding polypropylene, it enabled Camira personnel to gain a greater understanding of the underlying science.

However the satisfactory undertaking of Strand (ii) enabled the company to improve their overall process and so achieve the more immediate and commercially-driven objectives and hence impact of the research. A full analysis of the variables relating to the construction of a range of commercial fabrics was complemented by the design and production of a series of experimentally woven fabrics in which yarn and fabric structural variables were carefully selected and controlled. Both fabric sets were analysed using limiting oxygen index (LOI) and high temperature LOI techniques in order to assess relative fabric flammability behaviour for correlation with the French “M test” results. The variables of fibre colouration pigment, yarn linear density and fabric area density chosen for experimentally woven series of fabrics was based on the results of the analysis of the commercial fabric range. The colouring pigment(s) present within the component fibres was found to have a significant influence on the flammability of the resultant yarn and hence fabric. Thermal stabilities of different pigments commercially used for colouring PP fibres were also studied and the results used to predict their effect on flammability of the fabric. While the outcomes of this study failed to find absolute correlations between identified variables and final “M-test” performance, overall, the company was able to improve its understanding of the problem, introduce greater control of relevant production variables and so enhance the overall flame retardant polypropylene quality and resulting woven fabric performance. This has led to a significant increase in the profitability of this fabric brand.

Inspired by this research Cheryl Kindness, Director of Camira Fabrics started her PhD by publication and published her first paper in 2008 (Reference 1 in Section 3).

The parallel EPSRC and Dstl funded project (2003-2007) with Kandola as Investigator in collaboration with Universities of Salford (later moved to Bolton, Dr Hull (now Prof at UCLAN) and Prof Price) and Sheffield (Prof Ebdon and Dr Hunt)), Acordis UK, Rhodia Specialities UK Ltd, and Unifi, UK collaborative studied inclusion of nanoparticles in synthetic fibres and demonstrated nanoparticle/FR synergism in polypropylene and polyamide 6 filaments. This helped in understanding the synergism between different components in more depth (Ref 2-4, 6 in Section 3 and 3,4 in Section 5)). The project was rated ‘tending to internationally leading’ by EPSRC review panel. In a subsequent US Army Research office funded project (Natick, 2010) ultrasonification in the polymer melt has been used to improve the dispersion of nanoparticles and flame retardants; this research is still ongoing through a PhD programme (Ref 5 in Section 3).

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

1. C.Kindness, B.K.Kandola and A.R.Horrocks, Chapter 23: The effect of yarn and fabric construction and colour in respect of red reflectance and pigmentation on the thermal properties and LOI of flame retardant polypropylene fabrics. In : ‘Fire Retardancy of Polymers: New strategies and Mechanisms’, Ed. T.R.Hull and B.K Kandola, Royal Chemical Society, Cambridge (2009) pp 359 – 377.
2. A R Horrocks, B K Kandola , G Smart, S Zhang, T R Hull, ‘Polypropylene fibers containing dispersed clays having improved fire performance. I. Effect of nanoclays on processing parameters and fiber properties’, J Appl Polym Sci, 106 (3), 1707 – 1717 (2007). (Submitted in RAE 2007)
3. G Smart, B.K.Kandola, A R Horrocks and D Marney, ‘Polypropylene fibres containing dispersed clays having improved fire performance Part II : Characterisation of fibres and fabrics from nanocomposite PP blends. Polym. Adv Technol, 19, 658 - 670 (2008).

4. B K Kandola, G Smart, A R Horrocks, S Zhang, T R Hull, P Joseph, J Ebdon, B Hunt, A.Cook, 'Effect of different compatibilisers on nanoclay dispersion, thermal stability, and burning behavior of polypropylene-nanoclay blends', J Appl Polym Sci, 108 (2), 816 – 824 (2008).
5. A.R. Horrocks, B. Kandola, G.J.Milnes, A.Sitpalan and R.L.Hadimani, 'The potential for ultrasound to improve nanoparticle dispersion and increase flame resistance in fibre-forming polymers, *Polym. Degrdn. Stab,* 97, 2511-2523 2012.
6. B. K. Kandola, Chapter 24 : Flame Retardancy Design for Textiles. In: Fire Retardancy of Polymeric Materials, Second Edition, Ed. A.B.Morgan and C.A.Wilkie, CRC Press, London, 2009.

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

Because of their excellent abrasion and tensile properties coupled with relatively low cost, polypropylene fibres are widely used in manufacturing upholstery fabrics for domestic and contract (eg office, hotels, etc) furniture and automotive floor coverings. Flammability is a significant issue of priority for all sectors of the textile industry due to public safety awareness and stringent regulations controlling the use of products used in public buildings and transport, for example. The disappointingly low levels of achievable flame retardancy, coupled with their ease of melting, severely limit the use of PP yarns in a number of FR applications, however. Polypropylene is difficult to flame retard because: 1) its physical and chemical structures is not suitable for a facile incorporation of reactive flame retardants, 2) high loadings (5-20% w/w) of additives are necessary to confer flame retardance which often both creates processing problems and reduced mechanical properties.

The research carried at Bolton comprised both a fundamental investigation of the underlying fire retardant science coupled with a full analysis of the company's manufacturing process and related fibre/yarn/fabric structural variables. This has enabled Camira fabrics to produce a commercial range of contract upholstery fabrics having consistent fire test performance under the brand name Perfentex. Within this range and in particular, the Citadel and Chateau Plus, have achieved a higher specification of flame retardancy than other commercially available upholstery fabrics which has enabled Camira to develop sales into new geographical and commercial sectors. Since the development of their improved fabrics, sales amounting to £15,157,374 to date have been achieved. The fabrics have been used in public arenas and buildings throughout Europe, increasing the export market for FR polypropylene products over the last eight years significantly. In proportion the export sales of these products has been on average 50% of total sales of value £15,157,374.These furnishing fabrics can pass the required commercial flame retardant tests (notably the French "M-test") and hence, can protect public at large from fire (Ref 2 in Section 5). This has also helped declining UK textile industry in keeping a competitive edge against far eastern competition.

From research point of view, the research has created further interest. The EPSRC/DSTL project of £520K (2003-2008) developed high performance, thermally stable and flame-retardant fibres from polymer nanocomposite materials. Solvay (formerly Rhodia UK) a major UK flame retardant manufacturer and Camira fabrics have played an active part in this project and benefited from the know-how. The project has generated 22 peer reviewed publications, 2 MSc theses, and 16 conference presentations. The research was mentioned in EPSRC Newsline (see Refs 3 and 4 in Section 5). A key variable in optimising nanoparticle activity was found to be the need to maximise their degree of dispersion. Subsequently, the US Army Research Office funded ($50k, 2009-2010) a project to improve the dispersion of nanoparticles and flame retardant by using ultrasonification in the polymer melt. This research, which has been extended by a PhD student has generated two papers to date.

The director of Camira fabrics, Ms Cheryl Kindness registered as PhD by publication and used the knowledge gained for commercial exploitation.

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

1. A R Horrocks and B K Kandola, DTI Final report, ‘Developing the Next Generation of Flame Retardant Technical Polypropylene Yarns (FLAMTECH), DTI, February 2005
2. http://www.camirafabrics.com/fabrics/amherst
3. Fabric vs Fire: Research into nanocomposites could deliver tomorrow’s fire retardant high-tech textiles, EPSRC Newsline No 25 June 2003.
4. ‘Synthetic Stay Cool’, article by E Russell in EPSRC Newsline, Issue 35, 2006, pp 14-15.
5. EPSRC project (EPSRC (GR/S24367/01) and DSTL, Ministry of Defence (Dstl/02/JGS/352.1) final report, 2007.
6. Kandola BK, Report number W911NF-09-1-0574, project. The use of ultrasonification in thermoplastic polymer melts to improve nanodispersion and efficiency of flame retardant species, report submitted to US Army Research Office, USA, 2010.