Institution: University of Leeds

Unit of Assessment: 9 Physics

Title of case study: The development of lightweight, high-impact-resistant polymer composites with wide-ranging commercial applicability

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

Workers at the University of Leeds researched, then developed and patented the 'hot compaction' process for the manufacture of single polymer composites [1]. In this process highly oriented polymer fibres are heated so that a proportion of the surface of every oriented element melts. Upon cooling, this skin recrystallises to form the matrix of a self-reinforced fibre composite. Important resultant properties include high stiffness and strength, lightweight and outstanding impact strength, leading to a material with crucial commercial advantage. The reach of this impact is demonstrated by commercialisation of the polymer composite over a wide range of applications including anti-ballistic body armour, sports goods (Nike, Bauer), lightweight luggage (Samsonite), audio speakers (Wharfedale) and radar covers for helicopters (Westland). Examples include Samsonite using the material Curv® to manufacture two new high profile product ranges (Cosmolite and Cubelite) and Bauer using it in their elite-level ice hockey skate range (SUPREME and VAPOR).

2. Underpinning research (indicative maximum 500 words; Leeds researchers in **bold**)

Over many years, fundamental polymer research has been carried out at Leeds in parallel with commercial development. The strategy has been to seek new materials and material improvements for rapid exploitation. The underpinning research divides into three sections: (i) invention of `hot compaction'; (ii) expansion of the polymer portfolio; (iii) focus on polypropylene.
(i) Preferred molecular orientation in a polymer leads to enhanced strength, stiffness and toughness, without increasing density. Background research by Professor Ian **Ward** of the University of Leeds led to the development of a process for producing high modulus melt spun polyethylene (PE) fibres based on these ideas. The original aim was to use these PE fibres to replace the role of glass or carbon fibres in a conventional polymer composite. However, the crucial novel idea, developed by **Ward**, plus Dr PJ **Hine** and Mr K **Norris** also of the University of Leeds, was to use the high modulus melt spun PE fibres as both the reinforcing and the binder (or matrix) phase of a polymer composite [2,3]. This was achieved through a process named 'hot compaction'. At a critical temperature, the surface of each individual fibre could be 'selectively' melted while retaining the fibre core. On cooling, the molten material recrystallises, binding the structure together producing a homogeneous all-polymer composite (in fact uniquely, exactly the same polymer) [4]. The original research was carried out on high modulus PE in 1993, under the EPSRC funded IRC in Polymer Science and Technology (GR/F37016/01, £10M, 1989-1994) [4]. This work led to the first patent at Leeds in 1997 [2] and established all the important aspects of the hot compaction process, such as the retention of molecular orientation in the melting range of the fibres, the width of the process window and evidence of epitaxial recrystallisation.
(ii) The British Technology Group (BTG) sponsored a two-year research project (£230k, 1993-1995) to examine other polymers, notably gel spun polyethylene fibres and polyethylene terephthalate (PET), leading to a further four patents covering the effect of crosslinking on hot compaction behaviour, the effect of slow cooling, the effect of fast cooling, and the hot compaction of amorphous polymers. BTG currently license all eight hot compaction patents.
(iii) Further crucial research results emerged from study of the manufacture of sheets, use of postforming to produce real parts, and detailed measurements of properties, especially for polypropylene, which showed the greatest commercial potential. Reference [5] from 2003 summarises the research undertaken to establish the important parameters that control the hot compaction behaviour of woven, oriented polypropylene. This work established the best route for making the commercial (Samsonite) hot compacted polypropylene materials (Curv®), by showing that the properties of the recrystallised matrix material are also very important to the properties of the final self-reinforced composite sheet. Reference [6] from 2008, which supported and built upon

the very important patent from 2003 [3], presents the most important recent research, on the advantages of combining an interleaved film with the hot compaction process. This breakthrough widened the window of processing temperatures to a commercially acceptable value and increased the interlayer bond strength, which is enables greater commercial exploitation by improving thermoformability of the hot compacted sheets [3]. This latest patent extends the lifetime of the patent portfolio to 2029.

3. References to the research (indicative maximum of six references; Leeds researchers in **bold**)

[1] The science and technology of hot compaction, **I.M.Ward** and **P.J.Hine**, Polymer, 45 1413-1427 (2004); http://dx.doi.org/10.1016/j.polymer.2003.11.050 [cited 71 times].
[2] **I M Ward**, **P J Hine**, **K Norris**, US Patent 5,628,946, filed 13 May, 1997.
[3] **I M Ward**, **P J Hine**, **K Norris**, WO 2004 103673, filed 21 May, 2004.
[4] The hot compaction of high modulus melt spun polyethylene fibres., **P.J.Hine**, **I.M. Ward**, R.H. Olley and D.C. Bassett., Journal of Materials Science, 28, 316-324 (1993); http://dx.doi.org/10.1007/BF00357801 [cited 119 times].
[5] The hot compaction behaviour of woven oriented polypropylene fibres and tapes. I. Mechanical properties, **P.J. Hine**, **I.M.Ward**, N.D. Jordan, R. Olley, D.C. Bassett, Polymer, 44, 1117-1131 (2003); http://dx.doi.org/10.1016/S0032-3861(02)00809-1 [cited 70 times].
[6] The use of interleaved films for optimising the production and properties of hot compacted, self reinforced polymer composites, **P.J. Hine**, R.H. Olley, **I.M. Ward**, Composites Science and Technology, 68, 1413-1421 (2008); http://dx.doi.org/10.1016/j.compscitech.2007.11.003 [cited 26 times].

4. Details of the impact (indicative maximum 750 words; Leeds researchers in **bold**)

The impact detailed here is corroborated in a letter from M. Vance Grant, Managing Director of PropexFabrics GmbH [A]. In particular: *"The Curv® self reinforced PP composite which is a direct result of the hot compaction technology as applied to polypropylene developed at the University of Leeds has become a very profitable business venture for PROPEX FABRICS"* [A].

Pathway to Impact
The impact started with a number of commercial paths developed in conjunction with the underpinning research. These paths led directly from the advances made with the composite polymer materials. Initially in 1994 it was evident that the hot compaction technology could have a significant commercial application [1]. A small spin out company VANTAGE POLYMERS was created under the auspices of Leeds Innovations with **Ward** as Managing Director and several full time and part time staff. This venture was initially funded by Hoechst Celanese as licensee of the Leeds high modulus polyethylene fibre technology, and later by the Ford Motor Company. The creation of the company enabled further progress on developmental work and commercialisation by Ward and M Bonner also of the University of Leeds, with direct support from PROPEX, BTG and other interested parties. In 2000, the commercial operations were sufficiently developed to transfer to BP AMOCO (now PROPEX FABRICS) under a major licensing deal. Then in 2002, PROPEX FABRICS set up the first commercial plant for Curv® self reinforced PP composite at their site in Gronau Germany [B].
The first impact that led from the licensing deal with PROPEX FABRICS occurred in 2005. Samsonite pioneered the use of Curv® to produce a new range of lightweight, and impact resistant luggage as part of their premier X'Lite collection [C]. "*Samsonite's use of CURV composite is a revolution in the industry, providing the worldly traveler with the best in performance*," says Quentin Mackay, Samsonite's Global Creative Director [C].

Impact during the REF period
The impact has expanded massively following the initial success of X'Lite. In 2009 Samsonite extended the use of Curv® to a higher volume and more cost effective range of suitcases, the Cosmolite range [D]. The Cosmolite range continues to be a successful product for Samsonite and has received very favorable reviews from consumers and experts alike [E]. In 2009-2010 the Cosmolite suitcase was the number 1 seller of the whole Samsonite range. It was also the highest

selling suitcase in Europe in 2009-2010, with contribution to Samsonite's total net sales increasing from 0.4% in 2008 to 7.5% in 2010 [F]. Successive generation of Samsonite suitcases based on the Curv® single polypropylene composite included Cubelite® (2010) [G] and Firelite® (2012)..
This is both an economic and an environmental impact. Economically, Samsonite has experienced a massive growth in sales since the introduction of the Curv® material. This distinct and material contribution for polymer technology can be seen through the 34% increase in sales on year ending 31st December 2011 [H]. This is a clear indication of how significant the technology has been to industry on a global level. Indeed, the 2011 Annual report reports (Financial Highlights on page 4) that in addition to the 34% increase in net sales there has also been an increase of 56.6% in adjusted net income and a 47.2% increase in adjusted EBITDA [H]. The environmental aspect of the impact can be seen from improved quality of the Samsonite suitcases. The composite material is lighter, more durable, and more efficient to produce than materials previously used by Samsonite.
A second impact, also of economic and environmental significance, that has come from the licensing deal with PROPEX FABRICS is the introduction of the Curv® material to the manufacturing of audio technology in the loudspeaker industry. Indeed, the loudspeaker consulting group Menlo Scientific describe how the University of Leeds originally developed the composite polymer technology before BP Amoco aquired the technology and created PROPEX FABRICS to commercialise the process [J].
A third important economic impact has been in the market of sporting goods. Bauer manufactures elite level hockey skates (the SUPREME and VAPOR lines, both using Curv®), and had 69% of the market share for ice skates worn by USA professional National Hockey League players in 2011 [M,N].

Continuing Development and Impact
The reach of the composite polymer impact can be clearly seen from the multi-partner industrial collaboration project FuturePlas [K]. In 2006 Leeds were part of a successful Technology Strategy Board (TSB) proposal focused back on PE materials (Future Plas – Generating the next generation of single polymer composites, £250,000 2006-2008). The research undertaken showed that the incorporation of an interleaved film was even more important for these highly crystallised materials, which normally have a very narrow melting range. Using a film it was shown that sheets with significantly improved stiffness and strength could be obtained. Following this, an EU FP7 research project (hivocomp.eu, £600K, 2010-2014, with Leeds, PROPEX, SAMSONITE, and 4 EU academic partners) was set up to focus on achieving radical advances in composite materials for cost effective, higher-volume production of high performance carbon fibre reinforced parts. The project is analysing and developing self-reinforced composites based on thermoplastic polypropylene and polyacrylamide, hybridised with carbon fibre, with potential further high impact application in the automotive, aerospace, and luxury luggage sectors. In addition another spin off company was formed RIGICOMP headed by **Ward** which extends the hot compaction technology for the manufacture of self reinforced technology [L].

Summary
To recap, the underpinning research outlined in Section 2 created a range of high-impact-resistant polymer composites, through cost-effective and commercially exploitable methods. Polypropylene was identified as the most appropriate polymer for which a wide reach of the technology was applicable. A wide range of applications has been developed for the material Curv®, including anti-ballistic body armour, sports goods (NIKE, BAUER), and lightweight luggage (SAMSONITE).

5. Sources to corroborate the impact (indicative maximum of 10 references; Leeds staff in **bold**)
The supporting letter from Propex and all the web pages used as corroboration of this impact are on record at Leeds, along with all relevant documents as pdfs. All web pages and links last accessed 26/09/2013.

[A] Corroboration letter from M. Vance Grant, Managing Director, Propex Fabrics GmbH. For reference, the Curv® website is at http://www.curvonline.com/ .
[B] Article describing how Propex Fabrics set up the first commercial plant to manufacture the Curv® material, in Gronau, Germany in 2002.

http://www.frost.com/prod/servlet/meawards-hall-of-fame-feature.pag?mode=open&sid=45553709
[C] Press release on the introduction of Curv® by Samsonite to their suitcase range. http://www.netcomposites.com/newspic.asp?3295 .
[D] Samsonite website with details of the Cosmolite collection as of 25/06/13 http://www.samsonite.co.uk/cosmolite/collection-en.htm?or=5250052377&shs={422d9bce-1fca-489d-b33b-ad3c75ff2655} .
[E] Review of Cosmolite luggage http://www.bestcovery.com/samsonite-cosmolite-27-spinner-luggage , the lightweight and strength properties of Curv® are essential to the good reviews; customer reviews of Cosmolite on amazon.com, http://www.amazon.co.uk/Samsonite-Cosmolite-85cm-Suitcase-Silver/dp/8962457482/ref=sr_1_4?ie=UTF8&qid=1348502632&sr=8-4 ; http://www.europeanconsumerschoice.org/house/samsonite-cosmolite-luggage-reviews/ ; YouTube video of advertisement from Samsonite, focussing on the impact strength of the product and highlighting Curv® technology http://www.youtube.com/watch?v=vvpIBl4y1tc.
[F] Summary of Samsonite sales information up to 2010. Pie Chart showing net sales of the various brands of Samsonite International for 2009 to 2010 (p. 141); Cosmolite sales details (p. 128): http://www.hkexnews.hk/listedco/listconews/sehk/2011/0603/01910_1089087/E116.pdf.
[G] YouTube video (2011) of Samsonite announcing the launch of its new Cubelite® range. http://www.youtube.com/watch?v=bUw1ggJgwW8
[H] Samsonite International S.A. 2011 Annual Report http://hub2.samsonite.com/investors/_investordocs/20120424044355_E%20-%202011%20Annual%20Report.pdf .
[J] Article in the trade magazine *Voice Coil* (2007) describing the introduction of the Curv® material to the audio speaker industry with particular reference to the University of Leeds as the innovator of the material (p. 2). Available through www.audioXpress.com archive; pdf on file at Leeds.
[K] Webpage describing the role of the University of Leeds in relation to the the FuturePlas Project. http://www.futureplas.com/Partners/UniversityofLeeds/tabid/67/Default.aspx
[L] Article describing the formation of company RIGICOMP with **Ward** as a Director. http://www.compositesworld.com/news/rigicom-to-focus-on-self-reinforced-composites
[M] Bauer 2011 prospectus www.bauerperformancesports.com/pdf/
[N] Bauer-Propex press release announcing exclusive multiyear partnerhip with Propex to use CURV in elite level ice hockey skates http://www.propexglobal.com/propex-bauer-partnership/