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UOA: Electrical and Electronic Engineering, Metallurgy and Materials (UOA13B)

Case Study 2: *Lightweight Self-Reinforced Plastics for Ultimate Recyclability*

1. Summary of the impact

Research carried out by Prof. Ton Peijs and colleagues has led to significant breakthroughs in engineering plastics: PURE® and its licensed Tegris® technology, which are lightweight self-reinforced alternatives to traditional polypropylene (PP) composites such as glass-fibre or natural-fibre-reinforced PP. Environmentally friendly and 100% recyclable, these strong and ultra-light self-reinforced plastics have been successfully used across a number of applications, from suitcases and sports gear to protective armour and automotive panels, with impressive results. When used for car, truck and van components, they have been shown to help lower exhaust emission levels and increase fuel economy.

2. Underpinning research

Research in self-reinforced polypropylene (SR-PP) commenced in 1999 when Peijs joined QMUL from Eindhoven University of Technology. The 'PURE' research project was initiated by Peijs in the fall of 1998 and was supported by the Dutch Government through their Economy, Ecology and Technology (EET) programme. This collaborative project, led by Peijs ran until 2004 and included 4 industrial partners including Lankhorst Indutech (Sneek, The Netherlands). The QMUL research team led by Peijs and funded through this EET programme drove the project from the start and involved two PhD students (Norbert Cabrera and Ben Alcock), together with several project students focusing on the process development and characterization of high strength tapes and SR-PP (or all-PP) composites. The research team was complimented by another PhD student and researcher at Eindhoven, where Peijs maintained a part-time position to lead this team. From 2002-2004 the QMUL research team was complimented by two postdoc funded through an EU FP5 project ORTHOFLEX (G5ST-CT-2002-50185) and a DTI project ENVIROCOMP, focusing on developing thermoforming technologies for these SR-PP materials. A patent was filed in 2001 on the concept of self-reinforced polypropylene composites by Lankhorst Indutech with Peijs as co-inventor (WO/2003/008190; Polyolefin Film, Tape or Yarn) and the first results were published from 2003 onwards [1-6].

Polypropylene already has many advantages as it has the lowest environmental impact of all petroleum-based polymers, but on its own it is not strong enough for many engineering applications such as in automotive parts. Normally PP has to be reinforced with glass- or natural fibres to make it strong and stiff. However, the addition of these reinforcements makes recycling more complicated, time-consuming and expensive, ruling out the advantages of this useful plastic. Because of legislation such as the End of Life Vehicle (ELV) directive, materials selection is now strongly driven by recyclability and for this reason mono-materials are preferred. However, if automotive panels are to be made from non-reinforced bulk PP they simply have to be made thicker, or strengthened with extra ribbings, which would make these parts heavier, defeating the industry's quest to find lightweight alternatives to metals, as in transport applications the environmental impact of materials is largely dominated by potential weight savings through improved fuel efficiency and emission reductions.

PURE® 'all-PP' composites are unique in that both the reinforcement and matrix are made of the same material. They have specific ecological advantages over traditional composites based on glass- or natural fibres since they are entirely thermoplastic and can be re-melted at the end of the product's life cycle without the need for a fibre recovery process. Self-reinforced PP takes normal PP and by heating and stretching treatments it aligns the molecules to make the end product 10 times stronger and stiffer, without any weight gain [1,6]. The technology is based on highly engineered co-extruded tape which consists of a high strength and high modulus PP core and a specially formulated thin PP copolymer skin for welding the tapes together using heat and pressure [1,2]. This process of co-extrusion and tape welding gives enormous processing advantages over other 'SR-PP' alternatives such as Curv® as these co-extruded tapes exhibit a much larger

processing window (20-30°C to 1-2°C for Curv®). The tapes can be woven into fabric and can be hot-pressed together into sheet. Parts can be produced by thermoforming [5] or can be moulded directly from fabric using filament winding, compression, autoclave or vacuumbag moulding, or can be combined with PP foam or honeycomb into fully recyclable lightweight sandwich panels [4].

In recent years, Peijs' research into all-polymer composites has moved towards other polymer systems such as HDPE, PET, PLA, cellulose and aramid [6]. Many of these programmes were in collaboration with industrial partners such as DSM Dyneema, Novameer, Dow Chemical, Teijin Monofilament, Shell and GE Plastics. Peijs' team assisted in the development of high-strength high-density polyethylene (HDPE) tapes and self-reinforced HDPE composites (KAYPLA™) This work on SR-HDPE, in collaboration with Novameer BV (The Netherlands) was initially aimed at developing a cost-effective alternative for the anti-ballistic market, but is currently also used in panels for caravans and vans. After a buy-out by Japanese fibre giant Teijin for ~£10m in 2010, Novameer became part of Teijin Monofilament (became Nextrusion GmbH). KAYPLA™ tape is currently being produced by Compomeer in Greece, with UD and cross-ply sheet production in The Netherlands. High strength polyester (PET) tapes were developed for higher temperature resistance products in collaboration with Dow, GE Plastics (became Sabic Innovative Plastics) and later also Teijin Monofilament (became Nextrusion GmbH). Fully biobased all-polymer composites are currently being developed based on polylactic acid (PLA) in the framework of the EU FP7 Matera+ programme 'HIGHBIOPOL'. Since 2003 our research in this area has been published in over 30 papers in international peer reviewed journals together with a large number of invited international conference and key-note papers. One of the PhD students (Norbert Cabrera) received the 2005 Dow Energy Dissertation Award for his research in the area of sustainable use of energy and sparing the environment. The award included a prize of €2500 for his winning thesis entitled 'Recyclable all-polypropylene composites'. After his graduation, Dr. Cabrera was hired by Pure Composites to lead their R&D in the area of composite processing. As recognition for his work on self-reinforced plastics Peijs received the Dutch Polymer Award of Polymer Technology Netherlands (PTN) in 2008 and the Swinburne Medal & Prize of the Institute of Materials, Minerals and Mining (IOM3) in 2010.

3. References to the research

1. Peijs T., Composites for recyclability, Materials Today, 6(4) 2003, 30-35
2. Alcock B.; Cabrera, N.O., Peijs T. et. al., The mechanical properties of unidirectional all-polypropylene composites, Composites Part A: Appl. Sci. Man., 37(5) 2006, 716-726
3. Alcock, B., Cabrera, N.O., Barkoula N.-M., Peijs, T., Low velocity impact performance of recyclable all-polypropylene composites, Composite Sci. & Techn., 66(11-12) 2006, 1724-1737.
4. Cabrera NO, Alcock B, Peijs T. Design and manufacture of all-PP sandwich panels based on co-extruded polypropylene tapes. Composites Part B: Engineering, 39(7-8) 2008, 1183-95.
5. Cabrera NO, Reynolds CT, Alcock B, Peijs T. Non-isothermal stamp forming of continuous tape reinforced all-polypropylene composite sheet. Composites Part A: Appl. Sci. Man., 39(9) 2008, 1455-66.
6. Alcock B, Peijs T, Technology and development of self-reinforced polymer composites, Adv. Polymer Sci., 251, 2013, 1-76.

Funding:

Research that led to the PURE® technology led to the following grant awards:

- ORTHOFLEX: an EU FP5 collaborative project on 'stiffened SR-PP vacuum formings for orthoses to improve patients' comfort and mobility'. The project included 8 companies from UK, Netherlands, Denmark, Sweden, France, Belgium, and 2 R&D Institutes (Pera and QMUL), 2002-2004, £125k.
- SustComp: a DTI Sustainable Technology Initiative on 'efficient and environmentally friendly moulding of recyclable composites structures' with 5 UK industrial partners, 2002-2004, £40k.
- INTELTEX: an EU FP6 collaborative project 'intelligent textiles' using our co-extrusion technology to create high strength electrically conductive bicomponent tapes. The project included 12 industrial partners including UK partner Peratech, 2006-2009, £230k.
- HIGHBIOPOL: an EU FP7 Matera+ project on 'SR-PLA composites for engineering

applications', including 3 partners, 2010-2013, £250k.
- In addition it led to various industrially funded projects with GE Plastics, Dow, Shell, Novomeer, Teijin Chelton Radomes, totalling £250k.

4. Details of the impact

In 2003 the PURE® technology, initiated through the 'PURE' project and co-developed by Peijs' and his team at QMUL was commercialized through Lankhorst Pure Composites BV in The Netherlands, a division of the Royal Lankhorst Group, one of the original partners in the 'PURE' project. The material is targeting application markets ranging from recyclable lightweight automotive panels to suitcases, flight cases, helmets and sports equipment. In 2006, the PURE® technology was licensed to Milliken & Company in the U.S., the world's largest private textile firm, who are now marketing this technology under the trade name Tegris®. Pure Composites BV currently employs around 25 employees in The Netherlands and Portugal for the production and marketing of the product, with a similar number employed at Milliken to support Tegris®.

***Automotive*:** SR-PP composites have opened the door to a vast range of lightweight recyclable car, truck and van parts. Applications include: under body shields, interior panels, load floors, scuff plates and panelling for trucks and vans. The strong and ultra-light parts help to save weight (30% compared to glass-fibre-reinforced PP has been achieved) and lower exhaust emission levels and increase fuel economy. Because these materials are 100% recyclable, the material is ideal for use in automotive parts where the EU's End of Life Vehicle (ELV) Directive dictates recycling rates up to 95% by the year 2015.

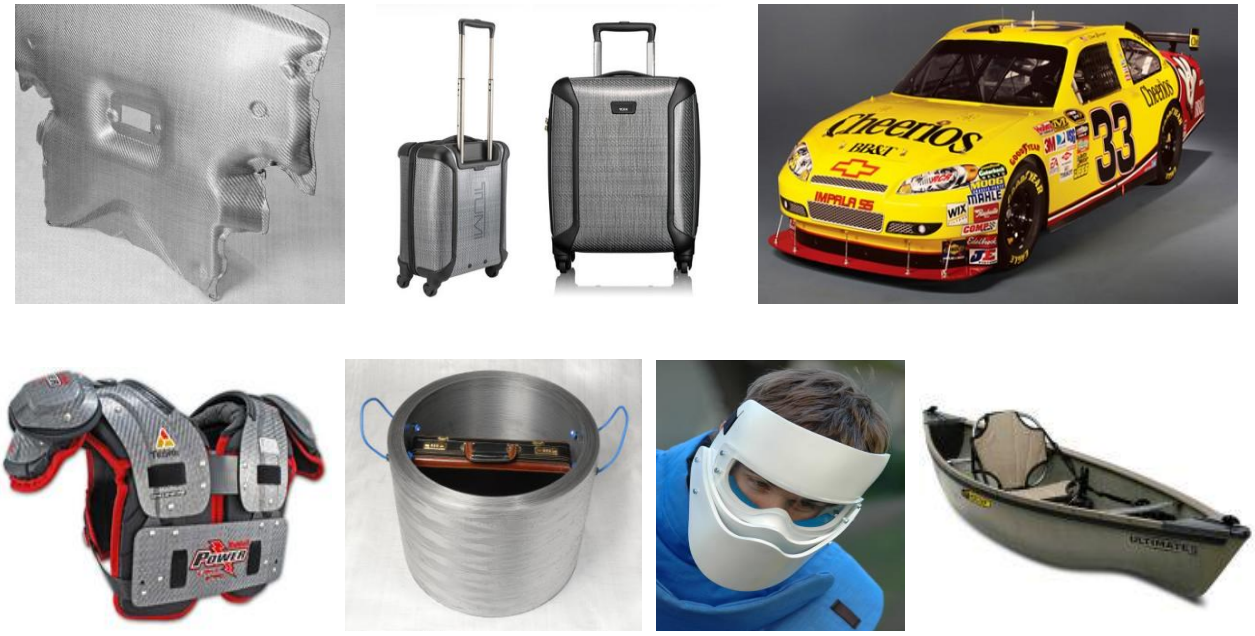
Luggage: TUMI Tegra-Lite's premium luggage collection was introduced in 2012 and is produced from Tegris® composite material from Milliken & Company. Self-reinforced PP is ideal for hard shell luggage applications where impact resistance, stiffness and weight are primary concerns. Tegra-Lite combines an industrial aesthetic look, with a design that is 65% lighter than glass fibre composites and provides up to 15x improvement in impact resistance over typical thermoplastics, while it maintains this performance level at low temperatures (-40°C), far exceeding other comparable pieces of commercial hard-sided cases on the market today. PURE® is also used for impact resistant flight cases, attaché and iPad cases. TUMI is the world's second largest producer of hard shell luggage and their Tegra-Lite series is available from large department stores like Macy's or Selfridges as well as online retailers like Amazon.

***Motor racing**:* The motor racing world has adopted SR-PP in a number of ways. Powerstream's Aero splitters based on Tegris® were introduced in 2011 and are now being used in NASCAR racing, as well as for door panels to replace carbon fibre. Self-reinforced PP is not as light or as stiff as carbon fibre composites; but it has about 70% of its strength at about 10% of the cost. One of the most important reasons for its use in motor racing besides its lightness, superior impact resistance and low cost, is the fact that it does not splinter when it breaks, which prevents having sharp pieces of splitter lying on the track after a crash, improving driver safety. The material is also incorporated in the new DeltaWing racer, developed by Chip Ganassi Racing for the American IndyCar series.

Protective armour: Tegris® is used in life saving protective armour by the U.S. military in its vehicles, primarily against improvised explosive devices (IEDs) or roadside bombs. Milliken qualified Tegris® for a number of military armour applications and in 2010 they have shipped 20,000 Tegris® armour kits for vehicles deployed in Iraq and Afghanistan. Predominantly flat panel systems for spall liners, these kits are used to retrofit vehicles for enhanced protection. Norwegian company ROFI Industries AS have developed their Armadillo De-mining Mask against humanitarian mine action (HMA). The mask, which is made from PURE® is lighter, stronger and more comfortable than existing de-mining masks and has proven to be effective in demining operations. The mask won the Index Award 2007, an international design award to promote design that improves life. Another outfit that appreciates the lightness and toughness of the material is Riddell, makers of body armour for American football players. Its Custom Power® Lightspeed Shoulder Pads™ was introduced in 2010 and are claimed to be the lightest in the business without compromising protection. PURE® is also used for helmets and other sports gear.

Blast Basket: Parcel bombs, either real or suspect are a potential problem for security agencies, major corporations and targeted groups. The PURE® Bomb or Blast Basket, is placed over the suspected object and protects property and personnel from the blast and fragmentation occurring when an IED is set off. It captures most of the metal fragments and redirects the blast waves upwards, protecting civilians. For example, a 35 kg blast basket, 400 mm high with a 500 mm diameter, can handle a 1 kg TNT bare explosive charge.

Kayaks: The Ultimate™ 12 Kayak from Legacy Paddlesports in the U.S., was introduced in 2007 and was one of the first commercial uses of PURE® or Tegris® in a large 3D part, creating the strongest, lightest kayak on the market. SR-PP is used because of it high stiffness and high impact resistance, so it can shrug off hard landings and damage from rocky bottoms. Other applications are in skis, snowboards, and surfboards.



Self-reinforced polypropylene composites based on co-extruded tape technology (PURE and Tegris) are being used for a wide range of applications incl. (from top left to bottom right) automotive undershields, luggage, motor racing parts, protective sports gear, bomb baskets, de-mining mask and kayaks.

5. Sources to corroborate the impact

- www.pure-composites.com
- www.milliken2.com/MFT
- Director Lankhorst Indutech, and Managing Director Pure Composites BV (1997-2008)
- Business Development Manager, Pure Composites BV, Sneek, The Netherlands
- Business Development Director, Milliken & Company, Greenville, South Carolina, U.S.A.
- Research Manager KAYPLA™, Novameer BV, and Compomeer BV, The Netherlands