Institution: 10007822

Unit of Assessment: 12

Title of case study: Nano-reinforced composite engine components: new business secured for the automotive supply chain

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

Lightweight engine components for cars, buses, trucks, vans, industrial engines and machines are now used by automotive manufacturers such as Volkswagen Brazil, Daewoo, Leyland Truck and Buses and Russia Machines. Our research work has been employed in a series of automotive components (engine oil pans of 1.2, 1.6, 1.8, 2.2. 4, 10 litres oil capacity) through various original equipment manufacturers, primarily Eaton and Cummins. Depending on the amount of integration, the materials cut 10-15% of the weight for a basic oil pan configuration and 40% of the integrated oil pan system.

2. Underpinning research (indicative maximum 500 words)

Cranfield's research into lightweight structures and polymer nanocomposites underpins advances in materials tailoring, structural-property relationships, thermo-mechanical performance, structural design and optimisation strategies in the design and manufacture of components. The work tailors the polymer/nanoparticle to achieve improved and balanced thermo-mechanical performance, and creates organized assemblies by exploiting depletion interactions/phase separation of nanoclays and other nanoparticles. Use of thermoplastics and other lightweight materials also aligns the UK's original equipment manufacturers (OEMs)[1] with the EU's vehicle end-of-life directive in that by 2015, vehicles must be constructed of 95% recyclable materials, with 85% recoverable through reuse or mechanical recycling and 10% through energy recovery or thermal recycling[2].

The research stems from demarcation of molecular and structural features that contribute to the mechanical properties of thermoplastic composites [G1, G2]. This led to significant improvement in impact resistance and performance of thermoplastic oil pans as desired by automotive industry. The work initially looked into experimental and analytical techniques to investigate failure mechanisms of short and continuous fibre-reinforced composites as a function of loading and environment conditions [P1, P2].

A wet-engine oil sump (oil pan) is an important component in an engine. The key concerns in the use of a thermoplastic oil pan are that it must not only contain the oil but also have a structural role. As one of the lowest parts in the engine, oil pans must also resist localised impact loadings such as that imparted by roadway debris. A failure on the oil pan base wall would lead to leakage and could result in a catastrophic engine failure from oil starvation. Our motivation was to improve, predict and assure the structural integrity of a wet-engine oil pan during its functional life in the vehicle.

This work led to further research into application of nano- and micro-sized fillers [G3]. Preliminary work indicated different reinforcing effects due to interface structure and dynamics [P3]. We exploited the idea of combining multi-scale fillers into a three-phase reinforced composite, a very attractive solution for future lightweight structures with balanced thermomechanical performance [G2, G4]. The research was also underpinned by EC Framework 7 funding grants [G4, G5].

Our research showed that novel materials avoid negative effects of micro filler, such as a reduction in material ductility [P5]. For example, we developed improved nanophased energy absorbing sandwich structures using polyurethane nanofoam exploiting the microcellural foam cells [P4, P6]. This established that (i) the incorporation of montmorillonite resulted in a higher number of PU cells with smaller dimensions and higher anisotropy index, and (ii) their nanophased sandwich structures resulted in improved repeated impact performance with less structural damage.

A key insight in this work was the discovery that some of the pristine nanoparticles used as fillers in nanoreinforced composites are released from polymer matrices to the environment during functional life of the products as original nanoparticles and in compound [P5]. These results give new insights into nanoparticle behaviour and will advise on future nanomaterial risk assessment, self-healing behaviour and depletion of particles reinforcement and durability issues [G2, G5].

Key researchers	Post details*	Dates involved	Research
Prof. K Kayvantash	Professor	2008-2010	Durability and impact performance [G1,G2]
Dr J Njuguna	Lecturer	2005-2013	Durability and impact performance, Nanoparticles release and emission, Thermo-mechanical performance [G1,G2,G4,G5]
Dr H Abhyankar	Research Fellow	2012-2013	Nanoparticles release and emission, Thermo-mechanical performance [G2,G4,G5]
Dr J Fan	Research Fellow	2011	Nanoparticles release and emission [G2,G5]
Dr H Zhu	Lecturer	2010-2013	

* highest grade in period given

[1] *King Review of low-carbon cars – Part I (2007) and Part II (2008)*
[2] *European Union's 2015 EU End Of Life Vehicle Directive for sustainability in the recycling of 'end of life' cars*

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

P1 * Z. Mouti, K. Westwood[a], K. Kayvantash, J. Njuguna, Low velocity impact behavior of glass filled fiber-reinforced thermoplastic engine components, *Materials*, **3**(4), pp. 2463-2473, 2010. doi: 10.3390/ma3042463

P2 * Z. Mouti[a], K. Westwood[a], D. Long[a], J. Njuguna, An experimental investigation into localised low- velocity impact loading on glass fibre-reinforced polyamide automotive product, *Composite Structures*, **104**, pp. 43–53, 2013. doi: 10.1016/j.compstruct.2013.03.014

P3 * F. Silva, J. Njuguna, S. Sachse, K. Pielichowski[c], A. Leszczynska[c], M Gianocolli[d], "The influence of multiscale fillers reinforcement into impact resistance and energy absorption properties of polyamide 6 and polypropylene nanocomposite structures," *Materials and Design*, **50**, pp. 244–252, 2013. doi: 10.1016/j.matdes.2013.02.041.

P4 J. Njuguna, S. Michalowski[c], K. Pielichowski[c], K. Kayvantash, A. C. Walton "Fabrication, characterisation and low-velocity impact on hybrid sandwich composites with polyurethane/layered silicate foam cores", *Polymer Composites*, **32**(1), pp. 6–13, 2010. DOI: 10.1002/pc.20995

P5 S Sachse, F Silva, A Irfan, H Zhu, A Leszczyńska[c], K Pielichowski[c], V Ermini[b], M Blazquez[e], O Kuzmenko[f], J Njuguna, "The effect of nanoclay on dust generation during drilling of PA6

nanocomposites", Journal of Nanomaterials, **2012**, Article ID 189386 (8 pages), 2012. doi: 10.1155/2012/189386

P6 S. Sachse, A. Irfan, H. Zhu, J. Njuguna, "Morphology studies of nanodust generated from polyurethane/nanoclay nanofoams following mechanical fracture" *Journal of Nanostructured Polymers and Nanocomposites*, **7**, pp. 5-9, 2011. doi: org/10.1155/2012/189386

* 3 identified references that best indicate the quality of the research

Key

a: Eaton, Automotive Group, UK; b: Laviosa Chimica Mineraria, Italy; c : Krakow University of Technology, Poland; d: Grado Zero Espace Srl, Italy; e :RTD Department, Spain; f: Palladin Institute of Biochemistry, The National Academy of Sciences of Ukraine, Ukraine.

Further evidence of quality – underpinning research grants

G1 EPSRC Case Award PhD. Impact behaviour in thermoplastic automotive engine components, (EPSRC and EATON) EPSRC; £163,000, 2007-2011. PI Dr J Njuguna.

G2 EPSRC DTA Award PhD. Thermo-mechanical properties of polyamide nanocomposites for automotive applications. (EPSRC and EATON), £200,000 2012 - 2015. PI Dr J Njuguna.

G3 EC FP7 Project No.: 228536-2. Nanomaterials related environmental pollution and health hazards throughout their life cycle (NEPHH), total value €3,186,530 (Cranfield €728,368) 2009 – 2011. PI Dr J Njuguna, CI Dr H Zhu.

G4 EC FP7 Project No. 265838. Development of new light high-performance environmentally benign composites made of bio-materials and bio-resins for electric car application (ECOSHELL); total value €4,129, 558 (Cranfield €702,040), 2010 - 2013. PI Dr J Njuguna.

G5 EC FP7 Project (Project No.:309802) Continuous, highly precise, metal-free polymerisation of PLA using alternative energies for reactive extrusion (InnoREX), €273,566, 2012 – 2016. PI Dr J Njuguna, CI Dr S Sachse.

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

Our research played an important role in safeguarding oil pan business worth over £20M for Cummins, and securing new business (for Eaton) with Daewoo and Volkswagen Brazil after regained confidence in the component. The oil pan business contributed around 25% to the $1 billion revenue of Eaton automotive plastic business between 2010 and 2012 [C1].

Lightweight construction aims to preserve or even enhance a product's functionality while the product's overall weight decreases. The challenge was to maintain properties while improving the component's dynamic response. This research allowed a combination of analytical micromechanics methods, finite-element simulations of material microstructures, and continuum mechanics techniques to provide microstructure based prediction of macroscopic environmental-mechanical response [P1, P2]. This improved understanding of the materials behaviour and the development of predictive tools for component design, using the new material grade (PA6-i-35G) developed – which is now produced by Eaton's preferred supplier, BASF. The exact business value of this product is not public, but the price rose from US$2.50/kg to 5.50/kg and it shares around 25% of the 6.6 million tons global PA66 market share.

Our research accelerated adoption into modern products by de-risking Eaton's product design and production. The results accelerated the commercialisation of oil pans series for a variety of

engines. The work led to the creation of a dedicated thermoplastics unit within Eaton [C1] and a new dedicated plant in Czech Republic.

Cranfield's research has also led to rapid commercialisation of thermoplastic composites in the construction industry with EnDesign Ltd. This work looked into environmental degradation of thermoplastic composite for flooring during its life. The product is now in the market, having successfully addressed the drawbacks and is the 'first-choice' product in the Asian flooring market [C2].

Laviosa Chemicals adopted Cranfield's research in nanofiller manufacturing, in its products Dellite 72T and Dellite 43B C3. The studies on dynamics of structural components, during their functional and end-of-life cases, generated important information such as the effects of particle size, particle distribution, specific surface area, crystalline structure, surface reactivity, surface composition and purity. This information was utilised by Laviosa in generation for assessment of the fate and behaviour of nanomaterial products in life cycle assessment of nano-reinforced products. Tecnalia has also used the work to evaluate impact of nanoproducts, which expanded its business and now has a new nanosafety dedicated division [C4].

The US Consumer Products Safety Commission adopted our work in three White Papers on the release of nanoparticles from consumer products during use [C5]. This informs compliance with the regulatory framework for consumer and environmental protection where industry must evaluate and, if feasible, quantify, the risk of embedded nanoparticle released throughout their lifecycle as an integral part of their innovation and design process for nanotechnology enabled products and make this information available to the relevant regulatory authorities and consumers.

The research also contributed to new methods for measurement and lifecycle analysis of engineered nanoparticles for the European Commission's Working Groups tasked with drafting of the European Strategic Research Agenda for Nanosafety Research 2015-2020 [C6]. Consequently, the European Commission granted additional funding [G5] to develop regulatory methodologies for detecting and understanding the fundamentals of debris splinters (nano-scaled dust/debris) which aims to develop European policies on nanorelease from nanoreinforced products.

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

C1 Contact: Product Development Manager, Eaton, UK
C2 Contact: Product Manager, Endesign Limited, UK
C3 Contact: Coating & Plastic Product Manager, Laviosa Chimica Mineraria , Italy
C4 Contact: Nanosafety Unit Manager, Tecnalia, Spain
C5 Nanorelease; Measurement Methods for Release of MWCNT from Polymer Matrices, June 2012. Contact: Director, Center for *Risk Science Innovation and Application (RSIA)*, ILSI Research Foundation, Washington DC, USA
C6 Nanosafety in Europe 2015 - 2025: Towards Safe and Sustainable Nanomaterials and Nanotechnology Innovations http://www.ttl.fi/en/publications/Electronic_publications/Nanosafety_in_europe_2015-2025/Documents/nanosafety_2015-2025.pdf (last accessed November 2013).