Institution: Queen Mary University of London (QMUL)

UOA: 13B Electrical and Electronic Engineering, Metallurgy and Materials

Case Study 1: *Nanoforce Technology Ltd. Assists in the Development of Materials and Processes for Industry*

1. Summary of the impact

Nanoforce Technology Ltd. is a spin-out company wholly owned by QMUL, active in the field of polymeric and ceramic materials. Bridging the gap between academic research and industrial applications, Nanoforce has done business with over 100 companies since 2008, providing the key research expertise and specialist facilities to enable the development of new materials and commercial products, including Sugru® a room temperature vulcanizing silicone rubber, Zelfo® a self-binding cellulose material, and Biotex™ a range of high-performance yarns, fabrics and pre-consolidated sheets based renewable resources such as PLA and natural flax fibres. Nanoforce has been promoting the development and commercialisation of spark plasma sintering (SPS) since 2006, which resulted in Kennametal recently opening the first commercial SPS facility in the UK to produce advanced ceramic armour. Nanoforce's clients have included large multi-nationals such as DSM, Dow Chemical, General Electric, SABIC, L'Oreal, Shell, Sibelco, governmental agencies such as Defence Science and Technology Laboratory (Dstl), and a large number of SME's.

2. Underpinning research

The creation of Nanoforce Technology Ltd. was the result of Queen Mary's long history in fundamental and applied research in new materials and processes. Over the years' research activities at QMUL in the area of both structural and functional materials have focused on polymeric, ceramic and composite materials for a multitude of applications including lightweighting, healthcare, protection, sensors, and energy conversion and storage.

Queen Mary has a long history in polymer and composite research, and a long and distinguished track record working in the general areas of polymer and rubber physics, composite processing, failure prediction, as well as component design. In recent years a large research activity has been focused on nanocomposites (Peijs, Busfield, Bilotti), where a major effort is around the processing of multi-functional polymeric or elastomeric materials based on nanoclays and carbon nanofillers [1,2], with interesting mechanical, electrical, thermal and optical properties. Besides nanocomposites a significant research activity is in the area of polymer nanofibres (Barber, Peijs). Nanospider® technology is used for the creation of electrospun nanofibrous materials for a wide variety of applications such as filtration, textiles, medical and protection, with links to Dstl. Other more distinct areas of research are those of micro- and nano-encapsulation (Sukhorukov) and photoembossing for micro- and nanopatterning (Bastiaansen).

The team has also extensive research expertise in the area on natural fibres, cellulose and nanocellulose (Peijs) to create fully biobased materials with interesting mechanical and functional properties [3]. MRI researchers (Peijs, Bilotti) have a strong track record in the field of bio-degradable and/or bio-based polymers (e.g. PLA, PHB, PCL) and composites [4]. More recently the use of self-binding nanocellulose networks (from plants or through bacterial fermentation), as a method to make 100% cellulose-based binder-free materials has been explored [5].

Ceramics have always been a major part of the materials research portfolio at Queen Mary, and interest in this field remains as strong as ever. Over recent years ceramic research has broadened to cover functional ceramics as well as the more traditional area of structural ceramics. Research has recently been focusing on nanostructured ceramics and thermoelectrics. For the production of these materials the team (Reece, Yan) has unique spark plasma sintering (SPS) facilities at Nanoforce that allow densification of nanoceramic powders to be achieved with minimal grain growth. The group is also involved in the development of conductive ceramic nanocomposites using carbon nanotubes or graphene as a conductive filler [6]. Here the rapid sintering by SPS can preserve the structure of such carbon nanostructures, opening up the possibility to create multi-functional ceramic materials with improved mechanical, electrical and thermal properties.

The application and impact of the team's research was significantly enhanced by the creation of Nanoforce Technology Ltd. in 2005. Nanoforce was set up as a spin-out from QMUL with £3.1m of funding from the DTI and the London Development Agency (LDA) through the Micro- and Nano Technology (MNT) competition and was created to bridge the gap between academic and industry-led research to enable the development of new materials or improvement of commercial products using MRI's knowledge-base. Nanoforce is an independent research and knowledge centre and the MRI's *'Portal to Industry'*, with a focus on advanced materials processing. It provides a service that industry often fails to find within academia as its set up, using full-time employed researchers, allows academics to conduct applied research on industrial timescales (months) rather than academic timescales (years) through PGRs or PDRAs. This has proven to be highly valuable to industry. Moreover, it gives QMUL academics greater flexibility to conduct R&D projects (either collaborative, bilateral, or confidential short term contracts) with industry rather than through PhD or Postdoc programmes.

3. References to the research

1. Bilotti E, Zhang R, Deng H, Quero F, Fischer HR, Peijs T. Sepiolite needle-like clay for PA6 nanocomposites. Comp. Sci. Techn. (2009), 69(15-16):2587-95.
2. Bilotti E, Zhang R, Deng H, Baxendale M, Peijs T., Fabrication and property prediction of conductive and strain sensing nanocomposite fibres, J. Mat. Chem. (2010), 20(42): 9449-55.
3. Berglund, L.A. and Peijs, T., Cellulose biocomposites - From bulk moldings to nanostructured systems, MRS Bulletin (2010), 35(3): 201-207.
4. Goutianos S, Peijs T, Nystrom B, Skrifvars M, Development of flax fibre based textile reinforcements for composite applications, Appl. Comp. Materials (2006), 13(4): 199-215.
5. Soykeabkaew N, Sian C, Gea S, Nishino T, Peijs T., All-cellulose nanocomposites from bacterial cellulose. Cellulose (2009), 16(3): 435-44.
6. Porwal, H, Tatarko P, Grasso, S, Khaliq, J, Dlouhy, I., Reece, MJ, Graphene reinforced alumina nano-composites, Carbon (2013), 64: 359-369.

4. Details of the impact

Over the REF period Nanoforce has supported over 100 companies through contract research and provided key research expertise to enable the development of new materials or improvement of existing products. As part of their remit to the LDA, it has also provided business support to over 200 businesses in the London area. Since 2008, staff working through Nanoforce have generated £2,78m of income, which accounts to 17% of the MRI's total grant awards.

Research at Nanoforce has played a pivotal role in creation and improvement of businesses (incl. Sugru®, Zelfo® and Biotex™). It has supported and contributed to over 100 academic papers. Twenty-one people have worked for Nanoforce over the 8 years of its existence, and many more in other partnering companies as a result of their growth through interaction with Nanoforce. Through their experience gained, Nanoforce researchers have progressed to other research based jobs such as Head of Research at AFC Energy, and Advanced Manufacturing Engineer at Rolls Royce. Over 55 PhD students have been trained at the facility and the company has presented in over 60 national and international events. It has participated in over 30 knowledge-based collaborations, whilst providing vocational training to over 300 individuals.

Customers of Nanoforce include multi-nationals such as Dow Chemical, General Electric, SABIC Innovative Plastics, DSM, L'Oreal, Shell, Transitions Optical, Sibelco, governmental agencies such as Dstl, and a large number of SME's. Nanoforce has also entered into a number of exclusive partnerships for technology exploitation with industry. For example, conductive polymer fibres for smart textiles are developed in partnership with CNT producer Nanocyl S.A. (Belgium), while in the field of thermolelectrics a partnership agreement exist with European Thermodynamics. In the area of high performance fibres, Nanoforce has recently become the preferred research partner for DSM Dyneema (Netherlands). Dyneema is a world-leader in high strength polymer fibres and they have selected Nanoforce as their main research partner because of its expertise in fibre technology and its ability to conduct research in an industrial facing environment under full confidentiality. Nanoforce has helped develop several products as well as transferring knowledge acquired from research. Prime examples of these are the, Sugru®, Zelfo®, Biotex™ and

Kennametal case studies discussed below.

Sugru® : FormFormForm is a young and vibrant SME based company in East London. Its main technology (Formarol) is a room temperature vulcanizing silicone rubber, which is specially formulated for handle-ability and cure kinetics. Sugru®, the brain child of FormFormForm's CEO Jane Ni Dhulchaointigh, is the first commercial product based on this technology. It resembles modelling clay but sticks to almost anything and dries to a tough, rubbery finish. It allows single users to personalise, fix and modifying objects, devises or goods. Over 285,000 people in 138 countries are currently using it to make their stuff work better, or as the company puts it, Sugru 'Hacks things better'. In 2008, because of its expertise in polymers and rubbers (Busfield, Peijs, Bilotti), Nanoforce was asked to assist in the development of Sugru. Supported by a TSB Feasibility Award, Nanoforce helped to create the silicone material that would be sticky but would also cure at room temperature. It provided advice on optimal processing and production methods, and the formulation of the current materials is a direct result of work performed in the Nanoforce labs. In November 2009, with a minute budget, FormFormForm started to produce a small batch of products. These first 1,000 packets of Sugru, which took a month to make, sold out in six hours to customers in 21 countries and where an instant hit. In 2010 TIME Magazine listed Sugru alongside the iPad as one of the top 50 inventions of that year, and in 2012 Jane Ni Dhulchaointigh won the 'London Design Entrepreneur Award'. Currently Sugru is receiving massive attention by different medias, particularly social media, thus bypassing traditional routes to market. Nanoforce involvement in the development of Sugru had direct economic impact through increased sales and jobs created with FormFormForm now employing 30 people. It had sales of $1 million in 2011 and doubled that figure in 2012. It opened an office in America in 2011, the firm's biggest single market.

Zelfo® : Zelfo is a materials system that is based entirely on nanofibrillated cellulose fibres, where fibres mechanically interlock and self-bind via hydrogen bonding. Hence, no further additives or resins are required to promote fibre bonding, resulting in a sustainable and recyclable bio-based alternative to ones using synthetic resin systems, such as wood fibre plastic (WFP) or medium density fibre board (MDF). Zelfo was initially developed and patented by Zellform GmbH (Austria) in the 1990s. However, it needed a collaborative R&D program funded by the DTI (REFLECT, 2007-2010), involving QMUL's Nanoforce, InterfaceFLOR, Omodo (the original patent holders), and other industrial partners to successfully industrialize the concept. Within this collaborative project, Peijs' his expertise in cellulose and nanocellulose [3-5], led to optimized environmentally friendly processing schemes for Zelfo panels. Minimizing energy and resources (water/fibre), up-cycling of cellulose waste streams, and shrinkage of the material while drying were issues that were tackled. Significant environmental impact was achieved through the successful development of a number of mixed fibre products which utilised cellulose waste and recycled paper. Dr. Luca Achilli, at the time working at Nanoforce under the supervision of Peijs, moved in 2009 to InterfaceFLOR as an Innovations Project Manager to further develop the product. In 2011 Zelfo Technology GmbH was created to commercialise the technology, and with a view to accelerate industry take up an IP technology transfer to BASF (Germany) took place in 2013, while in the same year Interface Inc., a world leader in sustainability, also acquired a shareholding of the company. In September 2012, Zelfo Technology and House of Hemp (South Africa) formed a manufacturing alliance to up-cycle cellulose waste to produce binder-free, formaldehyde free, products for the building industry in South Africa. The plant will produce a range of products to serve the building market. Zelfo has been awarded a number of prestigious prizes. In February 2011, Zelfo Technology won two prestigious 'Rushlight Awards' for environmentally responsible products. In March 2011 Zelfo was voted 'Biomaterial of the year 2011' by the Nova Institute. In April 2012, Niche Snowboards (featuring Zelfo) was awarded the ISPO (leading sports business network in Munich, Germany) 'Eco Snowsport Product of the year' for their freestyle snowboard models.

Biotex™ : Composites Evolution is a young SME that since 2010 provides innovative, sustainable materials to the composites industry. The current Biotex range now being commercialised by Composites Evolution are a direct result of materials developed through the DTI project COMBINE (2007-2010), together with project partners like Netcomposites, Springdale Natural Products, John L Brierley, Sam Weller and Sons, and Tilsatec. The Biotex family includes a range of high-performance natural reinforcement yarns, fabrics (woven and non-crimp) and preconsolidated sheets suitable for composite applications. Standard grades include pure jute and flax fabrics, flax/PP, and flax/PLA commingled fabrics. Compared to traditional natural fibre reinforced plastics based on non-wovens

these materials provide improved performance, easy processing and weight savings. They are suitable for semi-structural and decorative applications in sectors such as automotive, construction, marine, sports and consumer goods. Biotex uses a unique Twistless Technology to ensure a high degree of fibre alignment, impregnation and performance, based on research insights obtained by Peijs [4] in an earlier EU FP5 TEXFLAX project (2001-2003). Within the COMBINE project Peijs and team were responsible for developing optimized yarn and composite processing technologies and property evaluation. The widespread use of these materials can have significant environmental impact as these materials can save weight, and are based on renewable resources. The research had direct economic impact as Composites Evolution currently employs five fulltime employees. Its turnover in 2012 was £150,000 and has doubled annually since its start in 2010, and is projected to sustain this growth for the coming 4-5 years, with the company moving into a new building within the next year. Automotive parts based on Biotex are currently under evaluation by a whole range of car manufacturers and have been approved by Jaguar Land Rover for their next generation vehicles. The material has been successfully introduced in the sports and leisure market including snowboards by Canadian producer Magine, skis and canoes, often for its superior vibrational damping characteristics. Other markets under development are in furniture and consumer electronics such as laptop and smartphone cases.

Kennametal Sintec : Nanoforce set up the first spark plasma sintering (SPS) furnace in the UK in 2006 (Reece). It has been promoting the development and commercialisation of the SPS technology by working with several companies in the fields of thermoelectrics, ferroelectrics and structural ceramics and composites. Kennametal Sintec Ltd in South Wales, have just opened the first commercial SPS in the UK as an outcome of working with Nanoforce and Dstl to establish a UK on-shore capability to produce advanced ceramic armour. It involves a £2m joint investment by Kennametal and Dstl, and has already created one new job.

Nanoforce has assisted in the development of a wide range of commercial products (from top left to bottom right): Sugru® a new self-setting rubber for fixing, modifying and improving stuff; Panel products made from Zelfo® based on 100% renewable or recycled cellulose fibres; Biotex™ natural reinforcement yarns, fabrics, preconsolidated sheets and Magine's snowboard; and SPS technology for the development of Kennametal's ceramic armour.

5. Sources to corroborate the impact

- Research Manager at FormFormForm Ltd.
- Research Manager at Interface Europe Ltd.
- Managing Director at Composites Evolution Ltd.
- Research Manager at Kennametal Ltd.