Advancements in Nanofibre Technology

I. Hosie*

*Revolution Fibres Ltd, 9A Corban Avenue, Henderson, Auckland, New Zealand
iain@revolutionfibres.com

ABSTRACT

Revolution Fibres Ltd is a global leader in nanofibre production and the creation of advanced textile products. Revolution Fibres has commercialized and manufactures products with various clients in the areas of filtration, skin health, composites, acoustics, biotech and anti-allergy bedding.

Nanofibre has huge potential. Most often created through a process called electrospinning, it can be readily functionalized, has incredible physical properties, and is very marketable. It is also easy to produce at research level – hence the high number of papers and patents in this field. But is the level of innovation reflective in examples of commercialization? Furthermore, with the ability to carry high loadings of functional additives including most nanotechnologies, has the true potential even been realised? Revolution Fibres is one company that bridges the gap between research and commercialization, focussing on manufacturing and product development with advanced materials for real-world benefit.

Keywords: nanofibers, advanced manufacturing, advanced materials, electrospinning, nanotechnology.

1 BUILDING THE NANOFIBRE REVOLUTION

Nanofibre is a platform technology with huge potential. Most often created through a process called electrospinning from a wide range of natural and synthetic substances, it can be readily functionalized to produce textiles and porous coatings with incredibly new physical properties with multiple value propositions in a wide range of markets.

In recent years, nanofibre research and development has grown dramatically, with new nano-fibrous materials and applications being reported in peer-review journals every month. Although the innovation and market growth signs are very encouraging (expected to reach nearly USD 1.2 billion by 2020 and USD 2.89 billion by 2024, with a CAGR of 24-27% [1]) it is still not clear what products or services the nanofibre market entails. Application areas are incredibly broad ranging: medical devices, filtration, electronics, composites, energy generation and storage, sensing, acoustics and more. However, commercial products that utilize electrospun nanofibre remains very limited, with air filtration and lithium-ion batteries seperators being the only sectors in which they are used extensively.

A growing range of innovative applications are being discovered and developed, responding to the trend of our technologies, devices and consumer goods getting smaller; coupled with humanities relentless quest for improvement. We are in an age where we continually explore new properties of materials, especially at the nano-scale. The potential to take the vast array of non-woven textiles to the nano-scale is an intriguing prospect and a strong commercial opportunity.

One reason for the lack of commercialisation of electrospun fibres is the small scale at which nanofibres are produced using the conventional electrospinning method (using needles). In recent years, a number of companies have developed new methods which are capable of significantly faster production than methods previously reported within academia. With these new technological advancements, the potential for the use of electrospun nanofibre in industrial applications has become more achievable and there are a growing number of companies being formed to develop an industry for nanofibre use.

The current state of the market sees early adopters of the technology, bar the filtration industry, primarily selling electrospinning machines, rather than nanofibre products. This then puts the onus on end users to become producers, or researchers to become manufacturers. Globally, there is a significant gap bridging nanofibre research and commercialization. There is a market gap for an expert facility to adapt nanofibre design and production to emerging uses.

Revolution Fibres is one company addressing this gap. It has created lab, pilot and industrial-scale electrospinning machines (using its proprietary Sonic Electrospinning Technology™) that have the flexibility and capacity to produce commercial quantities of nanofibre. Recognized as New Zealand's Most Innovative Business (NZ Innovation Awards 2012 Supreme Winner, Future Textiles Award Finalist 2017) and with strong engineering and scientific acumen (TechConnect Innovators Award 2014; NZ Engineering Excellence Awards 2012), Revolution Fibres has unique expertise and production capacity, and is well-placed to exploit nanofibre technology and develop high value applications within key export markets.

2 OPEN INNOVATION - TOWARDS COMMERCIALIZATION

Nanofibre is a remarkably diverse textile technology, with many materials a possibility. However to be commercially viable, the electrospinning process must be able to produce nanofibre at large enough volume and for a cheap enough to compete with existing alternative technologies or products. Nanofibre is borne out of the centuries-old, very competitive and cost-centric textiles market. In order to compete in the textiles, membranes and specialty films markets, nanofibres must offer distinct performance or production advantages such as:

- Improvements in surface area, porosity and reduced thickness and/or weight
- Use of materials and functional additives that would not withstand traditional fibre making techniques (e.g. high heat, high pressure)
- Textiles or membranes small enough to be used in miniaturised devices (e.g. electronics, implantable medical devices etc.)
- Ability to carry high loadings of functional additives

Currently, the nanofibre industry is a fledgling “technology push” market where hundreds of academic papers per annum are published, many exploring or referencing commercial applications. Conventional needle based electrospinning is a cheap, achievable “entry” into nanotechnology but it rarely translates into commercial scale electrospinning, so most research has to be re-configured to be commercially viable.

Partnerships with end-users or sector leaders is vital. In response, Revolution Fibres has developed Nanofibre Customisation Services designed to help nanofibre get out of the laboratory and into the marketplace. In this example, Revolution Fibres work directly with Clients on nanofibre product development from idea generation through to large-scale manufacture

2.1 Bridging the gap between advanced materials and commercial uptake

Like most Advanced Materials companies, Revolution Fibres has a technology platform, based around specialist IP and proprietary production methods. This could also apply to companies producing (for example) carbon nanotubes, graphene; nanoparticles; aerogels; multi-walled organic frameworks; molecular imprinted polymer; etc. Like most specialist Advanced Materials providers, Revolution Fibres has the expertise the market is looking for – and are commercially driven.

Most Advanced Material manufacturers pick one application and focus on that. Many are forced into this through investment strategies and this unfortunately “siloes” technologies into various markets that unleash only a fraction of the potential. In nanofibres case that is in air filtration, and battery separators. Entire nanofibre plants are devoted to this, but ask them to make a wound dressing and they aren’t in a position to do so.

Whatever sector you look at, industrial manufacturers have the same needs. They want materials that will give them competitive advantages or increased performance. They want to buy materials that already exist, at good market rates, from reputable suppliers. They are looking for specialists - they want to rely on their supply chain to have the expertise and the ability to improve these materials on request, or through their own R&D. And they don’t want to be solely responsible for the development and manufacture of these materials – the General Electric / 3M model of large R&D teams doing all manner of technologies is behind us.

Unfortunately traditional technology partners don’t meet the industry’s need. Universities and Research institutes have different motivations – patents, papers and PhD’s are the core focus. And while the advanced materials technologies continue to advance at rapid pace, the mechanisms of how they will be used in industry and at what price cannot be addressed. And even if the material fits an industrial clients needs – who will make it? And how much will it cost?

Open innovation is the new “buzz word” where industrial clients shop for specialist technologies to meet their needs, and work with those specialists to customize the technology for their requirements. Both industry and technology providers need to develop ways to work together to achieve common goals. The key understanding is that Advanced Materials must be adapted and customized to suit various industrial needs. There is no “one size fits all”. Industry must be prepared to pay for this customization, especially now as these materials are on the cusp of commercialization. The companies who work with advanced materials companies now will be in the strongest position to have competitive edge and IP ownership in the years to come.

Revolution Fibres’ business model is one of open innovation, accommodating nanofibre development from concept to large-scale manufacturing:

1. Technical Assessment: will nanofibre work in the chosen application?
2. Feasibility Projects: designing nanofibre to suit the need
3. Product Development: integrating nanofibre into a product
4. Pilot Production: production, logistics, development of Technical Specs
5. Manufacturing: specialised runs or under contract
6. Post processing: conversion, ultrasonic welding, heating

2.2 Involving a nanofibre manufacturer in research and development

Often companies or academic groups will conduct research and development on a new nanofibre-based technology, using laboratory apparatus, to a point where they have proven the concept, raised capital and are ready to scale up, only then engaging with a manufacturer. Due to the differences between laboratory-scale and commercial scale electrospinning apparatus, there is often a significant amount of additional development required to scale up the technology, sometimes requiring changing materials completely. These additional costs and delays could be avoided by including a commercial manufacturer in development activities much earlier in the project, before the process is optimised.

Another similar trend is for researchers to "spin out" their nanofibre research into new commercial ventures. While this is exactly what the technology requires, quite often the spinout company decides to become a manufacturer and has to then devote huge resources, new infrastructure and different skill-sets to produce their invention. In some cases it could be faster and cheaper (and better use of investment dollars) to sub-contract the manufacture of their nanofibre invention in order to devote their time and resources on the (not-insignificant) cost of commercialisation. This will reduce start up costs, allow for prototyping and pilot-scale production for samples, and bring new expertise into the venture.

Clearly this is a technology push market, with the rate of innovation (or invention) far surpassing the rate of commercialisation. Revolution Fibres believe product development and manufacture go hand-in-hand. Who better to design your product than a manufacturer of the technology?

3 TURNING NANOFIBRE INTO PRODUCTS

Revolution Fibres has developed and commercialised a number of electrospun nanofibre products, both with and without industrial clients involved, which are discussed below as notable examples of nanofibre-based products and technologies currently being commercialised.

3.1 Air Filtration

Nanofibre air filters have been on the market for a number of years. Nanofibres are particularly effective at stopping particles smaller than 0.3 µm with minimal impact on pressure drop. They can adsorb volatile organic compounds (VOCs), microorganisms, allergens, and other pollutants (e.g., tobacco smoke). With the continual rise in air pollution, "airpocolypse" events, and the IARC's recent classification of air particulates below 2.5 micron as "probable carcinogens", the demand for high efficiency filtration for buildings and personal use shows no signs of abating.

Nanofibres clear advantage is in personal filtration with high surface area, high efficiency coupled with low pressure drop – resulting in more breathable, comfortable masks for general or medical use.

The next phase of growth is in functional, "intelligent" filters that selectively capture pollutants of concern (VOC's, microbes and viruses, heavy metals, etc) using active ingredients. Examples of functional additives include nanoparticles (silver, platinum), metal-organic frameworks and bioactives. An example of this is Seta™ air filtration, developed for a home ventilation company, which is a range of air filtration products that incorporate a fine web of electrospun nanofibre loaded with antimicrobial manuka extract. The same technology is now being explored in personal respirators (facemasks) and as anti-allergy bedding materials, for example pillow liners, under the brand Nanodream™.

3.2 Nanofibres in composite applications

The composites industry, particularly carbon fibre, continues to experience rapid growth internationally as industries strive for stronger, lighter, and more energy efficient materials. The benefits of fibre reinforced polymer composites are well known and their use has become commonplace in high-tech applications requiring low weight as well as high strength, high stiffness and corrosion resistance. Despite these attributes, fibre reinforced composites generally suffer from poor impact resistance, poor fracture toughness and poor delamination strength. This is particularly the case when brittle thermosetting matrix resins are used.

Lightweight veils made from nanofibres can be used as an alternative to currently-used composite toughening methods such as nanoparticles. Electrospun thermoplastic nanofibre interleaving veils have been shown to improve the compression after impact (CAI), delamination resistance and the Mode I and Mode II interlaminar fracture toughness of composites [2]. Nanofibre veils have also been shown to improve the fatigue resistance and vibration-damping properties of fibre reinforced composite materials.

The first commercial electrospun nanofibre product aimed at composites reinforcement is Future Textile Awards 2017 Finalist Xantulayr™ - a lightweight nanofibre veil that can be easily incorporated between the carbon fibre layers of a composite structure. During curing, the resin infiltrates through the nanofibre veil and the result is a composite with increased impact damage resistance and fracture toughness without additional weight. Xantulayr™ is being used in a range of high performance sporting goods, automotive (F1) and aerospace applications worldwide.

3.3 Nanofibre Acoustic Applications

Sound control is a growing concern in many industries around the globe. Conventional methods of sound control including foams and fabrics have been used to date to absorb, reflect and diffuse sound to a certain degree. The challenge for traditional acoustic layers such as foams and various fibrous batts, is to increase performance whilst becoming smaller, lighter and less dense.

Phonix™ acoustic products, developed by Revolution Fibres Ltd, have been found to increase the sound absorbency of existing acoustic materials such as foams and non-wovens. Using the nanofibrous Phonix™ material, the furniture manufacturers Finewood Furniture and Haworth developed the Return Focus Pod, a sound absorbing office cubicle for reducing noise pollution in open-plan offices.

In addition, Phonix™ nanofibre technology has been shown to reduce the unwanted high frequency noise in sound recording and playback in audio devices; and is currently being used in drone "shrouds" to reduce noise from drones on the ground, or from mounted cameras.

3.4 Medical and Skincare Applications

Nanofibres are uniquely suited to many medical applications due to their structure, which closely mimics that of the extracellular matrix of many of the tissues in our body. Electrospinning allows for a wide variety of natural or synthetic polymers, including many FDA-approved materials, to be spun into nanofibre; as well as for functional additives, such as antimicrobials or growth factors, to be incorporated.

The use of nanofibres in tissue engineering remains in its infancy, but there can be no doubt that this is a fast growing market and it will require suitable scaffold materials as it develops. Another medical field well suited to the use of nanofibre is wound care. There are a number of companies producing nanofibre based wound dressings to exploit the advantages of nanofibres.

Revolution Fibres, too, has developed nanofibre dressings, aimed at the cosmetics and natural health markets. The actiVLayr™ skin delivery platform is a water soluble marine collagen fibre patch that can be loaded with a wide range of plant and fruit extracts that are clinically proven to improve skin elasticity, moisture retention and reduce the appearance of wrinkles and sun spots. actiVLayr® Anti-aging patches and Skin Repair dressings are examples of the myriad of potential products using nanofibres as the delivery platform. By adjusting the extract types (grapes, kiwi, blackcurrant, seaweed, etc), actiVLayr® can target various skin appearances/benefits.

3.5 Nanofibres as a Carrier for Functional Nanotechnologies

Electrospun nanofibre shows great promise as a carrier opf functional additives. Their high surface area and porosity allow for exceptional interaction with their environment (liquid or gas), which means that, with the appropriate functionalization, they are able to react with their target substance with great sensitivity. Furthermore, additives are encapsulated within fibres, or bound within the non-woven structure to make the additives easier to handle, safer to use, fit more manufacturing process lines and significantly reduce agglomeration.

Revolution Fibres' Sonic Electrospinning Technology technique has been shown to carry high loadings of functional additives – as high a 200% loading or 2:1 additive to polymer ratio. Examples include graphene, CNT's, MOFs, MIPs, aerogel, nanosilver, TiO2 and ZnO.

In other examples, coating nanofiber results in thin porous membranes with added functionality. With KODE Biotech Ltd, Revolution Fibres has coated their unique biofunctional fucntion-spacer-lipids with mass-produced electrospun nanofibre. Furthermore, Revolution Fibres is perfecting a range of post-treatment steps to incorporate conductive polymers into its range of nano-textiles. Having successfully incorporated PEDOT-based conductive solutions into a range of nanofibre fabrics, the potential of creating ultra-thin, high surface area conducting textiles is being realised, and Revolution Fibres is looking for commercial partners to refine this technology into finished components or products.

Finally carbon nanofibres are also beginning to find application across a raft of industries including electronics (heat management, EMI shielding, conductors), composites (polymers, resins, glass, ceramics, plastics), energy (batteries, catalysts and fuel cells) and medicine and life sciences (drug delivery, tissue engineering, implants). Carbon nanofibres represent the fastest growing market for nanofibres, especially in Li-Ion battery applications. Revolution Fibres is actively producing carbon nanofibre precursors from a bio-resource that shows significant potential in the above areas.

REFERENCES

[1] TechNavio, "Global Nanofiber Market 2014-2020", 2016; Grand View Research Inc "Global Nanofibers Market Analysis, Share, Trends and Forecast by 2024- Market Research report 2016

[2] Gareth W. Beckermann and Kim L. Pickering, "Mode I and Mode II interlaminar fracture toughness of composite laminates interleaved with lectrospun nanofibre veils," Composites: Part A 72, 11 - 21, 2015.