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High-performance polymers – a new era of development

High-performance polymers could hold the key to the development of new materials for additive manufacturing, as **Paul McCutchion** explains.

Polymers and polymer processing are well-established technologies at the heart of manufacturing. However, in many advanced applications, metals are chosen because conventional polymers either cannot deliver the required mechanical performance or are thermally vulnerable. High-performance polymers (HPPs) could overcome these obstacles and are set to transform materials use to offer more than just lightweight replacements for metals.

HPPs are defined as materials having operating temperatures, in air, exceeding 150°C, although some can operate continuously at much higher temperatures. Moreover, many HPPs are resistant to ionising radiation, corrosion, abrasion and stress-fatigue, have low toxicity, are lightweight, and because of their linear molecular structures, they are mechanically tough. Examples of these hardwearing HPPs include fluoropolymers, such as PTFE, modified phenolics, polyaryletherketones (PAEKs), polyimides, polyphenylene sulfide (PPS) and aromatic polysulfones (PSU).

Throughout the last century, HPPs have experienced periods of significant growth. During the 1980s, there was particular demand from the aerospace and electronics sectors. However, further growth has been restricted due to the limited range of materials, difficulty in processing and the complexities surrounding mass-manufacture. Research by the Centre for Additive Layer Manufacturing (CALM) and Exeter Advanced Technologies (X-AT) at the University of Exeter, UK, is being carried out in partnership with industry to look at ways to overcome these issues. Their aims are to improve HPPs and composite materials available to conventional manufacturing operations, such as injection and compression moulding, as well as advancing the new fabrication route of additive manufacture.

Above: Carbon fibre and polyether ether ketone (PEEK) chopped tape used for moulding thermoplastic composite parts.

Additive manufacture

Despite the excitement around additive manufacturing (AM) its role in making production parts from polymer materials has been relatively slow to develop in comparsion with metals. But, as advances continue and applications begin to evolve, there is a continuous need for lightweight advanced materials with enhanced functionalities and this is driving new developments.

Left: Thermoplastic composite mouldings designed to replace aluminium alloys in aerospace applications.

One of the technologies being used in AM is laser sintering, with PAEK polymers including PEEK, PEK and PEKK now available. These materials are frequently used in conventional manufacturing for applications ranging from aerospace and defence through to the medical implant industry (for example PEKK). Through research into the use of these materials for AM, laser sintering of high-temperature and high-performance engineering polymers and composites using the commercial EOS INT P 800 platform could be achieved.

An Innovate UK programme led by Victrex and supported by the Centre for Additive Layer Manufacturing (CALM) and six industrial partners is focussed on developing solutions as quickly as possible. This project involves polymer makers and suppliers, parts manufacturers, post-processors and end-users. It is exploring ways to create affordable new high-performance polymers and composite materials, with Victrex developing new grades of PAEK polymers specifically designed for additive manufacture.

This project is aimed at understanding the mechanics of laser sintering of HPPs with a particular focus on powder flow characteristics and the properties of laser-sintered parts. The research uses novel in-process powder tests with the aim of linking the results of flow, spreading and compaction tests to the material characteristics and overall part performance, creating methods for new material development.

With new grades of HPP material likely to appear in the very near future, the next area of development will be multifunctionality and the supply of materials to deliver applications with optimised properties for specific application. This involves developing HPP nano-composite feedstock powder for AM. Research into nano-composites and AM has been ongoing for many years. As early as 2010, a collobration with Airbus Group Innovations created the ultimate toughness and other properties by ultimate materials (UTOPIUM) concept, of embedding patterned, vertically aligned carbon nanotubes within AM layers, bridging the interlayer boundaries and providing continuously aligned reinforcement. This research is now being extended to include graphene and a range of other particles, with properties being enhanced and crystallisation behaviour influenced through reinforcement with metallic, ceramic or carbon-based particulates. This is achieved through a range of processes including dry mixing, melt compounding and milling, and solvent-based methods to create core shell structures. These can provide improved mechanical performance, electromagnetic shielding properties and thermal or electrical insulation or conductivity.

The use of composite materials in the future will mean that design of parts can be optimised with any additional shielding or components removed, dramatically reducing size and weight, while improving performance levels.

Research is not limited to laser sintering, with similar materials being developed for the fused filament fabrication market. To date, these systems have not been able to produce the same quality of parts as laser sintering, but they do offer a cost-effective solution and a market opportunity. This invariably also leads to a number of claims and counterclaims about capabilities of solutions. To overcome this, an in-house device was built based on a dual heating system which allows 3D deposition of a wide range of materials from general polymers, such as PLA or PP and engineering grades including nylon through to high-performance polymers such as PEI and PAEKs. This was produced to allow research to take place with a focus on understanding the development and use of materials together with the production of systematic methodologies for analysis. With new commercial machines coming on the market throughout 2017 capable of working with HPPs, it is expected that there will be further growth in this sector of AM, with the systems facilitating more compact and cost effective solutions. This will provide the opportunity to make high performing parts in remote locations and for wider distribution of manufacturing capabilities.

AM has long been recognised as providing an opportunity for enhanced performance through superior design, and these material developments across a range of AM technologies are expanding its potential.

Thermoplastic composites

The possibilities extend even further when reinforced with materials such as carbon fibre as part of a thermoplastic composite (TPC). In these cases, HPP composite properties far outshine traditional thermoset matrix composites in terms of toughness, without loss of strength or stiffness, while significantly enhancing the ability to recycle and recover the valuable raw materials at end of life. When high-performance thermoplastic composites were first developed and companies such as ICI began to produce PEEK and other materials (end of the 1970s), it was thought that these materials would revolutionise the composites industry and replace traditional thermoset-based composites. However, flexibility in manufacture remained the critical factor and constituted a barrier to the uptake of HPPs, with the major shift towards high performance TPCs only now starting to take hold.

HPPs are often difficult to process due to their high melt viscosities and processing temperatures, but research institutions and industry are working to overcome these issues and developing novel materials and solutions for future applications. One example is a project to produce lightweight wheel technology for aircraft by developing high performance thermoplastic composites, which could offer greater than 25% weight savings while operating in a highly demanding environment. The new products require excellent impact strength at low temperatures, high mechanical fatigue strength, low tendency to creep and must be able to survive a series of industry-specific tests, such as extended roll life, combined load and burst tests.

X-AT are also partnering on several other Innovate UK initiatives, focused on the development of lightweight automotive componentry, including a project aiming to deploy new formulations of thermoplastic composites and develop a mass manufacturing production method of lightweight components for low-carbon vehicles. The aim is to provide this emerging industry with a lightweight and cost-effective alternative to the heavy iron components used as standard for more than 50 years.

There is huge potential for HPPs with the development of new materials for additive manufacture and enhanced thermoplastic composites. Areas of planned research include continuing to deliver new material options with enhanced functionalities – improving processing through methods such as lowering melt viscosities through chemical modification and the development of HPP blends, investigating degradation processes to improve recyclability and finding new ways to manufacture by adapting conventional thermoset and thermoplastic manufacturing processes to suit HPPs.

This article was authored by Professor Oana Ghita (Academic Lead), Dr Luke Savage (TPC Research Lead) and Paul McCutchion (Commercial Manager) of X-AT and CALM at the University of Exeter, UK. The centres provide material science research and manufacturing expertise across a wide range of polymers and composites with specialism in high performance polymers.

Right: Additive manufactured PEEK and carbon nanotube impellers.

Below: PEEK air duct manufactured by laser sintering.

Below right: Selection of high performance polymers in pellet and powder form.