



Preface

On the reinforced polymer composites with optimised strength and fire resistance - In Memory of Arthur Geoffrey Gibson[☆]Alexander M. Korsunsky, Editor-in-Chief, Materials & Design^{*}*Oxford, United Kingdom*

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This Virtual Special Issue (VSI) provides an overview of the developments and achievements in the field of polymer composites with advanced mechanical strength and thermal resistance in the 21st century. It has been collated by the Editors to celebrate the life and work of **Arthur Geoffrey Gibson** who served as Editor of *Materials & Design* from 2015 to 2021. Geoff was widely recognised as a UK research leader in the field of polymer composite materials.

One of the major themes of Geoff's work was of **Thermoplastic Polymer Composites** (TPCs), in which he pioneered understanding through several decades of laboratory research, numerical modelling and experimental testing. He was involved in the commissioning of manufacturing facilities with industrial TPC partners across the world, as well as extensive publishing and editorial activities in the area. Geoff's other major enduring interest was the **performance of polymers and composites in fire**, in particular the ways of improving their resistance. His pioneering work led to solutions now employed widely in the construction and cladding of buildings, as well as in the offshore and maritime industries. A brief overview of these two fields is given in this Preface, along with the introduction of a [collection of articles](#) in honour of Geoff's major contribution to the field.

1. Structural TPCs – a brief history

Despite the significant improvements in specific stiffness and strength, the use of composite material in lightweight commercial applications was, for several decades, limited by insufficient understanding, reliable test methods and the certification that was required. Geoff's work on TPCs was pivotal in the push away from well-established metallic alloys in transport, aerospace and other performance-critical applications. The uptake for reinforced thermoplastics has been slower for the same reasons that once prevailed for thermosets, namely, lack of established design codes and material properties databases and a need for proven production technologies [1].

A key property advantage that thermoplastic composites offer compared to their thermoset counterparts is their several times superior fracture toughness and impact resistance [2]. Since these materials can be processed by softening and melting, they can be formed and re-formed depending on the need and can be recycled at the end of use. TPC production processes are fast and flexible and autoclave-free, while the emission of harmful compounds during fabrication does not represent a significant issue. Fibre placement processes and other modern automation routes can also be used, making TPCs well-suited for highly integrated structures.

In the specific context of the automotive sector, TPC parts can be made in a matter of a few minutes – a fraction of the time required to cure thermosets. On the other hand, thermoplastics

[☆] In memory of Professor Arthur Geoffrey "Geoff" Gibson^{*} Corresponding author.

are highly viscous compared to liquid thermosets before curing, meaning that complete fibre impregnation may present more of a challenge to ensure the required interfacial strength of the matrix-fibre bond. Given the relatively low melting temperatures, thermoplastics are also more likely to creep under load compared to thermosets. Additionally, some thermoplastics may degrade significantly under ultraviolet light. These considerations highlight the need for well-structured and documented testing and certification programmes to underpin further reliable and widespread use of TPCs.

Notwithstanding the limitations, high value sectors such as aircraft construction led the introduction of TPCs favouring high-performance resins, such as polyetheretherketone (PEEK), polyetherketone (PEK), polyetherimide (PEI), polyethersulphone (PES) and polyphenylene sulphide (PPS) [1]. Following this lead, automotive, ship-building and renewable energy sectors are following suit, along with the already widespread use TPCs for reinforced thermoplastic pipes.

The last decade has seen the development of a vast array of novel TPC production methods and applications, which have expanded the scope and use-case of this material class. For example, additive manufacturing/3D printing based methods have allowed the production of novel geometries and structures with enhanced thermal/mechanical performance that are suited for high temperature or biomedical applications [3,4]. Low density TPC foams can now be reliably tailored for a broad range of components including impact shielding and insulation [5], and electrospinning can be used to produce fibre mats for cellular scaffolds and substrates [6]. These new and exciting approaches are a snapshot of an expanding field, which will have a substantial impact on academia and industry going forward, with particular promise in helping address several arising societal and environmental issues.

2. Fire resistance of polymer composites

In many applications of polymer composites there arises a requirement for adequate performance in the case of fire. This is associated with the nature of the organic compounds from which these materials are produced, which are naturally combustible. These limitations were identified early in the evolution of composite materials, and significant research efforts have been directed towards improving their fire resistance since the early 1980's [7]. Initial focus was placed on two main mechanisms of fire retardance; the emission of gaseous phases to suppress flames, and condensed phase retardance in which the substrate is altered to reduce flammability. These effects can be achieved via the addition of additives, which historically primarily consisted of halogen-based media or intumescent paints, both of which have shown significant potential and success [8,9].

As highlighted by Geoff in his seminal work [10], the flammability of polymers poses several challenges. For example, there is a significant reduction in mechanical performance of polymers during exposure to flame, with a particular susceptibility to creep-induced failure [11]. The production of highly toxic fumes is also common for many widely used polymers, which has led to stringent regulations across many sectors. Reliable and representative flammability testing of polymers is also known to be challenging due to the broad range of temperatures and pressures that can be generated.

Despite these obstacles, polymer composite parts often quickly form a layer of protective char and can then sustain a significant proportion of strength over extended periods of time. This is helped by the onset of pyrolysis that has an endothermic nature and helps to reduce the temperature. The heat conduction of poly-

mer materials is also significantly less than metal counterparts which can help slow the rate of progress of fire. Additionally, with the onset of advanced modelling techniques, the performance of these materials in exposure to fire and extreme heat can now be reliably predicted [12]. The combined efforts of the research field over a span of several decades has also led to a series of standardised ASTM tests that can be used to assess the suitability of these materials for a broad range of applications [13].

Thanks to these efforts, polymer composites found increasing use in a broad range of applications in which the fire safety is crucial. This includes civil infrastructure, automotive, rail, marine and aerospace applications. The use of thick layups can significantly enhance the fire resistance in several structural applications. However, in transport or other lightweight applications this approach runs counter to the principal design objectives [14], and therefore thinner polymer composite members tend to require a form of fire protection. Thick film intumescent coatings have been used to protect pipes used on offshore rigs, but in other applications fire protection solutions used are typically of passive type, in the form of protective boards/panels [15] and sprayed-on materials [16]. The use of novel additives has also shown particular promise, with a diverse range of materials and suppression mechanisms now reliably employed [17]. Within the last decade this has included the establishment of nanomaterial additives which have been shown to increase thermal stability, reduce smoke production and minimise flame temperatures effectively [18].

Beyond these more accepted methods, a plethora of new fire-resistant polymers and production methods have been proposed recently. The rapid research growth on this topic has been accelerated by some recent tragedies and the resulting strong political/media interest in fire resistant cladding and structural polymers. New fields have begun to emerge, including the production of bio-based materials which are both flame retardant and environmentally friendly [19], as well as novel methods using waste products in order to provide enhanced fire resistance [20]. Aerogels are also emerging new material class that has the resilient mechanical properties and high thermal stability required for lightweight structural applications [21]. It should be highlighted that interest in the fire resistance of polymers continues to grow within both industry and academia, which will ultimately help to provide the materials, structures and components required to maximise fire resistance and safety.

The Article Collection presented contains a selection of articles on these chosen topics, including some of the recent publications handled by Prof. Gibson during his tenure as Editor of *Materials & Design*.

3. Arthur Geoffrey Gibson

Geoff was born in Newcastle upon Tyne where he attended the Newcastle Royal Grammar School. He went on to study Chemical Engineering at the University of Manchester and became interested in polymers whilst working at ICI after his first degree. He obtained MSc in Polymer Technology from Loughborough University, and later received their distinguished alumni award in 2013. In 1979 he was awarded PhD from the University of Leeds and joined the University of Liverpool as Lecturer in Materials Science and Engineering. In 1990 he took up the Roland Cookson Chair in Composite Materials Engineering at Newcastle University, and remained in this position until he became Emeritus Professor in 2018.

Geoff was a natural polymath whose career spanned a broad range of topics. He helped establish the NewRail Research Centre at Newcastle University that is now well-known for its world-class

work in transportation. Geoff helped formulate and adopt the American Petroleum Institute industry guidelines on reinforced thermoplastics that were published in the early 2000 s. His leadership in the early work on the fire behaviour of polymers and composites resulted in a seminal book published in 2006 with his friend Prof. Adrian Mouritz (RMIT, Australia) that has become established as a key reference for many aspiring researchers in the field [10]. The work pre-dated the Grenfell tragedy by more than a decade, but was already visionary in understanding the importance of understanding how polymers combust to ensure safety in buildings, as well as in rail and marine applications. More recently, Geoff played a major role in the success of the European project called FIRE-RESIST that captured the most up-to-date thinking on creating fire retardant composites for deployment in a wide range of applications.

Geoff loved teaching and led courses spanning first year 'strength of materials' to specialist MSc level courses on pipeline engineering and advanced materials and processes. He was a dedicated professor, delivering lectures in his own particular engaging style that students found enlightening. Later in his career Geoff was involved in the development of the partnership between Newcastle University and Singapore Institute of Technology that helps students to establish links with UK research.

Geoff's natural, effortless wit made him approachable and easy to talk to, and his unique ability to describe his work to a non-expert audience meant that he found it easy to make friends personally and professionally. He was particularly proud of his collaborations with industry in the fields of energy and transportation that pioneered the application of advanced composites. Geoff created the Composites Divisional Board at the Institute of Materials, Minerals and Mining and was its first chairman, promoting the visibility and importance of composites within materials science and engineering. He received the Institute's Holiday prize in 2000 for his contributions to the science of composite materials. His long-lasting legacy will be the many PhD students he supervised, as well as the younger colleagues he mentored and encouraged – including the present authors who are forever indebted to Geoff for his generosity of thought and spirit.

In 2015 Geoff took on the role of Editor in *Materials & Design*, as the journals lead in the area of polymers and composites. His natural ability to identify world class research, encourage new researchers, and pick up emerging trends has established the journal as a pioneer in the field. A fact that is clearly demonstrated by a doubling of the journal's impact factor since he took on this role.

Geoff, our respected colleague, and dear friend, died on 30th July 2021, following a period of illness during which he continued to serve as Editor until his final days. He will be missed by many and leaves a legacy that will be remembered fondly and broadly. Thank you for everything, Geoff.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests. The personal relationship with Arthur Geoffrey Gibson to whose memory this collection is dedicated is declared in the text.

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