Materials and Structures

By Brian Cotterell and Yiu-Wing Mai

During the Nineteenth Century, Britain adopted the term '*strength of materials'* to describe the mechanical behaviour of solid materials. One of the first textbooks with this title was written in 1850 by Thomas Tate. Tate had assisted the noted engineer Sir William Fairbairn with the analyses of the designs for the Britannia and Conway bridges.[1] Although his title suggests that the main purpose of the subject was to determine *strength*, the main concern was actually the calculation of the stress according to the load. Even in the great Stephen Timoshenko's two-volume *Strength of Materials*, first published in 1930, only a single final chapter in the second volume discusses the actual mechanical properties of materials, as so little was known about the actual failure of materials at that date.

Despite its chequered past, the term *strength of materials* conveys the area of teaching and research involved in the mechanical behaviour of solid materials. Certainly to use any other term for this area prior to the 1960s would have been an anachronism, though the term has fallen out of favour today. Strength of materials was always one of the key research areas in the School, but during the last thirty years the physics and chemistry of materials have also been studied.

The Department of Aeronautical Engineering, which has now been combined into the School, was established in 1939 with A.V. Stephens as the first Professor. During the Second World War years the Department concentrated on aerodynamics, but after the War Stephens wanted to broaden the Department to include aircraft structures. Since he was a Cambridge man, he sought the advice of John Baker (later Baron Baker of Windrush) who was head of the Engineering Department at Cambridge. Baker recommended William Henry Wittrick, a young Cambridge graduate who was then at the Royal Aircraft Establishment, Farnborough. In 1945 Wittrick became, at the age of twenty-three years, one of the youngest men to be appointed as a senior lecturer at Sydney University. Under Wittrick, research and teaching of aircraft structures flourished.

The Early Engineering Years: William Henry Warren (1852-1926)

Although William Warren was effectively a professor of civil engineering, his work was a part of the history of strength of materials in the School until a separate department of Mechanical Engineering was formed in 1900. Warren published a number of books on the strength of timber, iron and steel (they went through many editions.[2]) He was also active in advising the New South Wales Government. He served on two Royal Commissions, one into railway bridges (1885-86) and the other into Baldwin locomotives (1892-93). In the latter Royal Commission[3] he examined the fracture of bogie and tender wrought iron axles, performing drop weight tests to show their unsuitability. The axles were made from scrap iron. When it was asked why there were no tests on the axles, the answer was 'because a test of one axle is no certain criterion of the strength of the whole of them'. The next question was 'why is steel more generally tested than iron?', which drew the answer that a phosphorus content as little as one percent could make the steel brittle, but it had been known as early as the Eighteenth Century that phosphorus could also make wrought iron brittle. The wrought iron axles were replaced by steel ones.

Thus the study of the properties of materials as well as mechanical analysis existed from the earliest times of engineering at Sydney University.

Materials Testing in the School

Warren purchased a Greenwood and Batley testing machine in 1884 that was a smaller version of the famous David Kirkaldy's 50 Ton (500 kN) testing machine.[4] He was able to expand his Materials Testing Laboratory considerably in 1909 when the Peter Nicol Russell Building was opened, and he purchased a million pound (4.4 MN) Amsler testing machine which is still in service in Civil Engineering.[5] These machines formed the nucleus of the Civil Engineering Materials Testing Laboratory.

The Department of Mechanical Engineering had a very meagre materials laboratory until the move from the Peter Nicol Russell Building to the present building in the Darlington Campus in 1974. Up until then the only testing machine was the Dalby Testing Machine which was designed especially for the P. N. R School of Engineering by Professor W. E. Dalby[6] and constructed in the workshops of the Sydney Technical School using funds special donated by Mrs Charles Kolling.[7] It was placed in position in a commemorative ceremony by Dr. R. S. Wallace, the then Vice-Chancellor of the University, in November 1936.

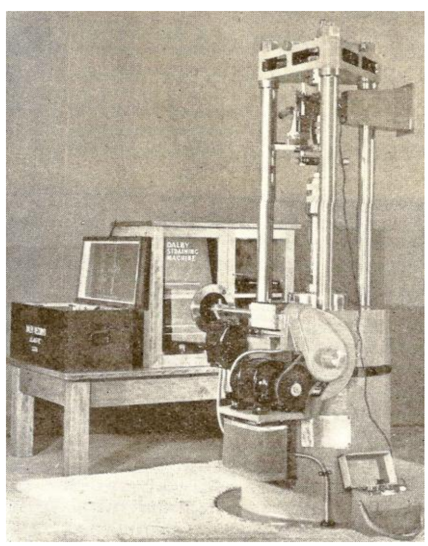

Figure 1 The Dalby Straining Machine

The machine had many features that were ahead of its time. It was a very stiff machine, much stiffer than present day Instron and MTS machines; it could be cycled from tension to compression and had unique auto recording equipment that produced a load-extension curve on a photographic plate. Up until the 1970s this remained the only Testing Machine in the School, though of course the Civil Engineering Materials Testing Laboratory (now the J. W. Roderick Laboratory for Materials and Structures) was freely available. The Dalby Testing Machine was donated to the Power House Museum in the 1970s.

A micrographic laboratory was built up in the 1960s for both research and teaching. When the School moved to the new Darlington site in 1976, two Shimadzu testing machines were purchased: a 500 kN universal hydraulic machine and a 100 kN servo-hydraulic machine capable of performing fatigue tests. The present well-equipped materials testing laboratory was built up from the late 1970s by Yiu-Wing Mai.

William Hope Harnet Gibson (1892-1967)

Gibson had a very long association with Sydney University. He graduated in Science in 1913 and in Engineering in 1915, after which he was appointed demonstrator in Mechanical Engineering. In 1921 he became a lecturer and retired as Reader in 1958 after forty-three years continuous service in the Department of Mechanical Engineering. His major research contribution to the strength of materials was in photoelasticity. Harold Bailey continued Gibson's work on photoelasticity, publishing a paper in Nature on the use of gelatine as a photoelastic material in 1959.[8] In the 1930s a Coker Polariscope had been purchased and housed in the Kolling Photoelasticity Laboratory.[9] Gibson (in collaboration with Pierre Mathieu Gilet, a Commonwealth Research Scholar in Mechanical Engineering), carried out noteworthy research on the transmission of torque by keys and keyways in the 1930s.[10] The torsion attachment shown in Figure 3 was designed by Gilet. Gibson also studied metal cutting in the 1950s.

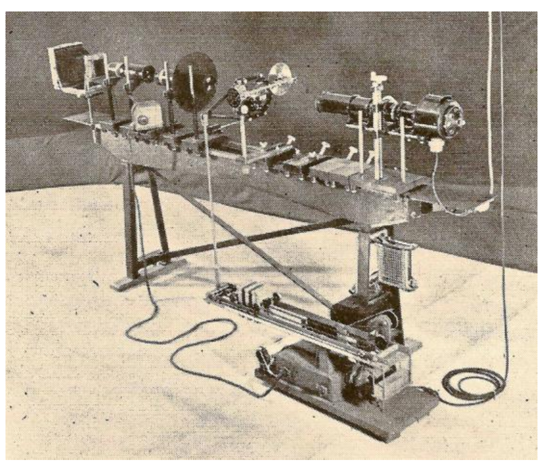

Figure 2 The Coker Polariscope showing torsion experiments in progress.

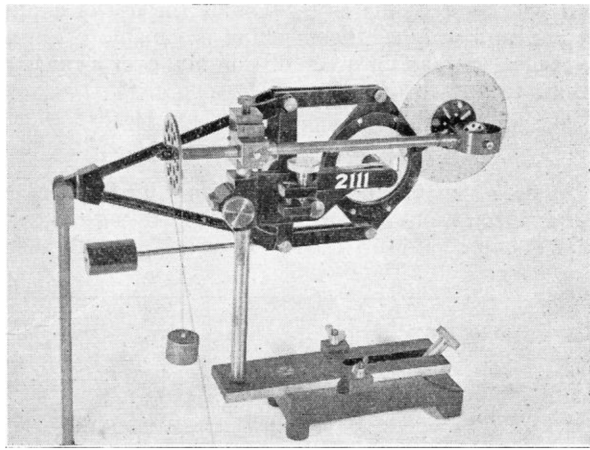

Figure 3 Torsion attachment for the polariscope.

William Henry (Bill) Wittrick (1922-1986)

After the end of World War II, research into high-speed swept winged aeroplanes was a priority at the Royal Aircraft Establishment. Wittrick brought an interest in the structural behaviour of such wings to Australia and he researched the coupling between flexure and torsion. In 1950, Wittrick became the first recipient of a PhD in the University, for a thesis entitled *Torsion and Bending of Swept and Tapered Wings with Ribs Parallel to the Root*. The thesis contained detailed numerical applications of his theory: no mean task when all calculations had to be performed with a mechanical calculating machine.

In the early 1950s Wittrick worked on the buckling of the wing panels. The papers he published on this topic formed a substantial part of the literature at the time. He also worked on the problem of thermal buckling. The Comet disasters of 1953 caused many researchers (including Wittrick) to study the stress concentrations around windows in aircraft fuselages. In the 1950s the analytical work of Mushkelishvili became known in the West through translations, and Wittrick applied this work to the stress around reinforced holes. Wittrick was awarded the 1960 Orville Wright Prize of the Royal Aeronautical Society for part of this work. In 1956 Wittrick succeeded Stephens as the Lawrence Hargrave Professor of Aeronautical Engineering.

An event that had great influence on Wittrick - as well as many other researchers at Sydney University - was the setting up of the Adolph Basser Computing Laboratory. This involved the purchase of a computer in 1956 from the University of Illinois which was appropriately renamed SILLIAC. Wittrick’s colleague Glyn Davies has given a graphic account of Bill's enthusiasm:

> The machine was as large as a double decker bus and its thousands of valves rapidly overtaxed the air-conditioning system, so that it was rarely one hundred percent reliable. Bill could be seen, with the few academics willing to embrace such a monster, loading, compiling, bootstrapping and

> diagnosing faults on the machine itself - including corrective measures such as hitting the valves with a rubber hammer....

With the advent of SILLIAC Wittrick's research reached new dimensions.

Wittrick returned to England to take up the chair of Structural Engineering at the University of Birmingham in 1964. Mansfield stated that Wittrick "thought it would be a good thing for himself and the vitality of the department if he were to move on".[11] However, Davies believes that Wittrick mainly moved back to England so that his two daughters could have a Cambridge education. Wittrick had made an outstanding contribution and in 1958 he was elected to the Fellowship of the Australian Academy of Science (FAA). He was also elected Fellow of the Royal Society (FRS) in 1980 after his return to the UK, the first Sydney engineering Professor to achieve this laurel.

Glyn A. O. Davies

Davies was head-hunted while working at Bristol Aeroplane Co. where a transfer from the Britannia and Concorde to Missiles was being threatened. The immediate reason for his recruitment to the Department of Aeronautics in 1959 was (according to Davies) that Wittrick wanted to take sabbatical leave at the College of Aeronautics, Cranfield, so needed someone to teach aircraft structures to third and fourth year students.

Davies, along with Wittrick, made good use of SILLIAC to test stress analysis around holes using Mushkelishvili's method. In part of this work he collaborated with Ted Buchwald from the Department of Mathematics. In his characteristically self-effacing way, Davies said that "our research output was pathetic in today's terms. We were better at cricket and defeated Mathematics several years running." In 1966 Davies was awarded a PhD for a thesis on *Plane Stress Problems in Doubly-Connected Regions*.

Although Mushkelishvili's method was elegant and fascinating, Davies could see that numerical stress analysis, being pioneered by Argyris at Imperial College, was going to be increasingly important. Since the Department of Aeronautical Engineering was going through a period of change (Bill Wittrick leaving and Tom Fink going over to Mechanical Engineering), Glyn decided in 1966 to join Argyris in the Aeronautics Department at Imperial College. He subsequently became Professor of Aerostructures and Head of Department.

David Robert (Bob) Axelrad (1910-1999)

Bob Axelrad graduated in Engineering in 1936, from the prestigious Technical University of Vienna. In 1949 he moved to Sydney to become the chief design engineer for Poole and Steel Ltd. By 1957 he had moved from Civil Engineering at the University of New South Wales to become a Senior Lecturer in the Department of Mechanical Engineering at the University of Sydney. He obtained a M. Eng. Sc. from Sydney University in 1959 for a thesis on the torsional stiffness of non-circular shafts. In 1963 he was awarded a DSc by the Technical University of Vienna.

As well as working on torsional problems, Axelrad was interested in high temperature creep. He published a book on the Strength of Materials in 1959.[12] Axelrad was a meticulous Austrian, the only man that Roger Tanner has known to always wear gloves while driving. It is probably unfortunate that he joined the Department before its revitalization by Tom Fink: he left in 1964 to become an Associate Professor at McGill University. He quickly became a full professor and had a very successful academic career working mainly on micromechanics.

Brian Cotterell

Cotterell was appointed by Tom Fink in 1962 to work in the strength of materials area. He came from the British Welding Research Association (BWRA) where he had worked under the innovative Alan Wells, mainly on the brittle fracture of low strength welded steel. Cotterell had joined the BWRA after postgraduate work on thermal buckling because welding has many thermal stress problems, but he quickly became more interested in the fracture work of Wells.

In the School of Engineering, Cotterell initially pursued his interest in the fracture of low strength steel. Although he received help and encouragement from the School of Metallurgy at the University of NSW, his early encounters with some Australians in this new and exciting field were far from encouraging. Two experiences, which still seem incredible, stopped him attending conferences or publishing in Australia for a few years.

In one incident at a conference in Melbourne, one influential Melbourne gentleman was critical not of the content of his paper, (which on looking back was not so good and warranted criticism), but of the validity of an engineer talking about the fracture of steel, which (in his view) was the province of a metallurgist.

The second incident occurred when another influential gentleman from Melbourne accused him of being obscene in a technical paper. In 1961, Wells had developed his concept of a critical crack opening displacement (COD), for which he designed what he called a *codimeter* to measure it. Cotterell in all his innocence used this term in a paper which he submitted to an Australian journal and was surprised when he received a letter from the editor accusing him of being obscene.

Australia was still very provincial in the early 1960s and these incidents should not have surprised Cotterell. A colleague at the BWRA had warned him about Australians even before he took up his appointment. This chap had worked in Melbourne for a few years in the late 1950s before joining the BWRA, and one day his wife was taken aside by other wives and told that people were talking about her husband because he was wearing a plain tie instead of a striped one (or it might have been the other way around). Fortunately, most Australians became more cosmopolitan during the swinging 60’s.

Cotterell soon became more interested in the fundamental aspects of fracture that were still being developed. He used a number of materials other than metals in this work including polymers, but initially he saw them more as model materials than as different materials. His major contributions to the fundamental aspects of fracture were a series of papers on fracture path directions starting in 1965, and the development of a new method of characterising the toughness of ductile materials. This he did using the essential work of fracture (EWF) concept which he formulated along with John Reddel, a Master's student, in 1977. Most of Cotterell's research after 1979 was in collaboration with Yiu-Wing Mai in the School.

Apart from his main research on the fracture of engineering materials Cotterell also developed other areas. In the early 1970s, Jo Kamminga, a PhD student pursuing research on Australian stone tools in the Department of Anthropology in the University of Sydney, knocked on his door to ask if there were any microscopes he could use. A productive collaboration grew out of this initial meeting, focused at first on the flaking of stone tools, but then it broadened out to include the mechanics of all pre-industrial technology. The collaboration has continued to the present day.

Another chance encounter saw an equally exciting development. All of us who work in engineering are used to amateur inventors knocking on our doors, usually with inventions that contravene the laws of thermodynamics. However, one day in 1976, a retired engineering naval commander called Pat Williams knocked on Cottrell's door with his invention: the split nut. This great new nut, which won the gold medal at the Geneva Salon of Inventions in 1977, is easy to fit and (more importantly) easy to remove. It is also stronger than a conventional nut. Helping to design this nut and analyse the reasons for its higher inherent strength were a challenge that Cotterell relished. To make the two halves of the nut identical, the thread needs accurate placing, and powder metallurgy was initially thought to be the only manufacturing technique to place the thread with the required accuracy.[13] The work on the production of the nut by the powder metallurgy route led to research on the fracture of sintered steel.

In the early 1960s the University of NSW's School of Metallurgy taught materials to our mechanical engineering students. Although they did a good job, a subject suffers in the eyes of students if it is not done 'in-house'. Consequently, Cotterell took over the materials teaching and built up a micrographic laboratory for experiments.

In the mid 1970s the Australian manufacturing industry was healthy. The Australian steel industry was performing well, the minerals boom was just starting (providing work on the construction of mining equipment) and polymers were being introduced in motor cars. A need was seen for a School course in production technology. It had not been previously taught so a course was designed. Subsequently, of course, the Australian steel industry declined, mining equipment and polymer parts for cars could be more cheaply produced in China and the need for a course on production technology declined, so the course only lasted about ten years. It would be very difficult to restart a manufacturing industry in Australia today because the expertise is no longer here.

In 1991 Cotterell, finding Australian taxation burdensome, decided to seek his fortune in Singapore. He returned to the School as a visiting professor from 2000 to 2012.

Ralph F. Scrutton

Ralph Scrutton was a metallurgist whose research on machining was seen as complementary to the fracture research of Cotterell. He was recruited by the School from the Division of Applied Physics of the CSIRO's National Standards Laboratory in 1965. Unfortunately, Scrutton only stayed until 1967 when he left for the University of Waterloo, Canada, and no collaborative research was developed.

Yiu-Wing Mai

Mai (as he prefers to be called) did his PhD on fracture mechanics with Charles Gurney at the University of Hong Kong. His postdoctoral research was undertaken with Tony Atkins at the University of Michigan on thermal shock of ceramics and high strength-high toughness composites, and with Gordon Williams at Imperial College on fracture and fatigue of polymers. This broad experience across a range of engineering materials prepared him well for his future career in Sydney. He was appointed a *short-term* lecturer by Roger Tanner virtually on the strength of a phone call to Gordon Williams (by accident Mai was in his office). The position was vacant because Paul Isherwood had declined the offer. Mai was very pleased because he had always admired Brian Cotterell's fracture research as a PhD student and was truly excited at the opportunity to work with Cotterell. He also thought that experience in Australia, after the US and the UK, would be beneficial to his academic career if he were to return to Hong Kong. He left London in early December 1976.[14]

In Sydney, Mai did not have an easy start. Research collaborations with Cotterell did not begin until 1979 when Cottrell returned from sabbatical leave at Brown University. From the late 1970s to early 1980s they undertook a project on the evaluation of fracture and mechanical properties of fibre cements using wood fibres to replace asbestos. This project contributed to the manufacture of a range of novel asbestos-free building materials and led to pioneering work on the (then new) area of fracture mechanics of cementitious materials with large fibre-bridging and/or matrix fracture process zones.[15] At this time Mai was working with Brian Lawn of the NIST on the crack wake grain-bridging model to elucidate the strengthening and toughening mechanics of coarse-grained alumina. His concurrent studies on fibre cements have many similarities. These R-curve and grain-bridging basic concepts have since revolutionised the microstructure design of toughened ceramics.

In the 1980's Mai and Cotterell extended the essential work of fracture (EWF) methodology to ductile polymers. This motivated much EWF research amongst laboratories in different countries. An ESIS testing protocol for toughness of polymer films[16] was set up due to the efforts of Gordon Williams. Mai and Cottrell undertook studies on constraint effects on ductile fracture toughness, fracture and cyclic fatigue of sintered metals, uPVC pipes and zirconia-bearing ceramics, and fracture characterisation of composites interfaces.

Teaching new subjects can generate new research. In the early 1980s, Mai taught a "biomaterials" component of an Electrical Engineering course on bioengineering, offered by Peter Nickolls, sparking his subsequent interests in this field. Greg Roger, a medical graduate from Sydney, undertook M.E.R. research on total revision HIPS with Mai and Cotterell and went on to a very successful entrepreneur-inventor-lecturer career. He is now Adjunct Associate Professor in Biomedical Engineering in the School.

Mai and Denis Yue of Medicine also collaborated on researching wound strength and wound healing affected by diabetes, a forerunner of tissue engineering in the School. Mai and Roland Bryant of Dentistry received the School's first NHMRC project grant (1992-94) to investigate the adaptation, fracture and wear of dental composite resin restorations. In some resins, both micro- and nano-sized inorganic fillers were used in UV-cured resins. Later Mai worked on polymer nanocomposites in a Federation Fellowship project (2002-07).

Mai was appointed to a Personal Chair in Mechanical Engineering in 1987. He was given some generous start-up money by the then Vice-Chancellor, John Ward, to establish the Centre for Advanced Materials Technology (CAMT). This money also enabled him to offer Michael Swain a part-time Visiting Associate Professorship (1990-92) to share his teaching load on a dental materials science course designed for the dentistry students. Swain is now Professor of Biomaterials in Dentistry.

Cotterell's departure for Singapore in 1991 presented Mai with a timely opportunity to convince the department to appoint three new lecturers, Lin Ye, Liangchi Zhang and Caroline Baillie, in 1992. By this time, the CAMT was well-established with excellent facilities. Its partnerships with the Cooperative Research Centre for Aerospace Structures (CRC-AS) and the DSTO Aircraft Engine Division's Centre of Expertise in Damage Mechanics (CoE-DM) provided new research directions throughout the 1990s. Close collaborations with different industry partners also opened up new applications-oriented research.

With the CRC-AS, Mai worked on the fracture mechanics of stitching and z-pinning, which are techniques to improve the delamination resistance of laminated composite structures. The models and analyses used echoed his earlier studies on single fibre pullout and crack-wake bridging. With supports from the CoE-DM and the Australian Research Council (ARC), Mai worked on the reliability of smart materials and devices, which posed complex nonlinear fracture mechanics problems of electromagnetic materials.[17]

In the 1990s, Mai initiated two research projects which pre-dated the now trendy "nanotechnology". One was on nanomachining and nanopolishing of damage-free contact lens made of biomedical hydrogels; this required a basic understanding of the mechanics of brittle-ductile deformation transitions. Another was on the fabrication and performance of superhard nanocomposites coatings on forming tools by the PVD process; this required basic studies on the physics and mechanics of microstructures evolution, residual stresses and fracture. It was an important step towards green manufacturing without coolants; and the project was continued when Mai was on leave at the City University of Hong Kong (2000-02).

In 1993-95, Mai had worked at the (then new) Hong Kong University of Science and Technology where he had helped to recruit new academic staff for its mechanical engineering department. Simultaneously he had begun research on the toughening mechanics and mechanisms of rigid-rigid polymer blends, which remained a focus area on his return to Sydney.

Mai took up one of the first fifteen Federation Fellowships in 2002, torn between Hong Kong and Sydney (see cartoon in Fig. 4).[18] The fellowship gave him uninterrupted time to develop a new research area of polymer nanocomposites towards multifunctional applications, particularly examining “nano effects” due to the incorporation of nanofillers like clay, silica, rubber, carbon nanotube and graphene into polymer matrices. Physics and chemistry were required for processing, characterisation and functionalisation studies. This led to his current work with Qipeng Guo on the toughening of nanostructured thermosets using reactive block copolymers and block ionomer complexes. Mai’s research today also covers energy composites and transparent conductive films fabricated by electrospinning techniques.

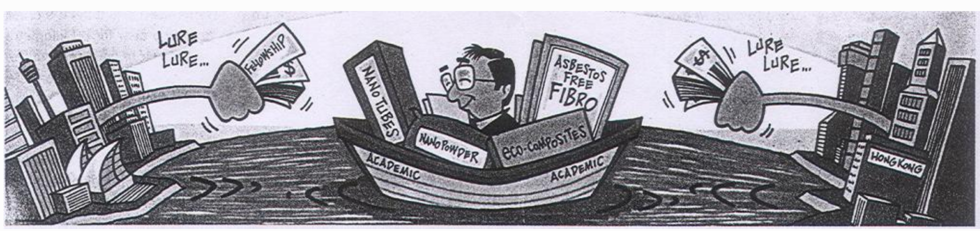

Figure 4 The lure of fellowship and dollars – which way? [18]

At the height of the AIDS epidemic in the mid-1980s, someone in either public health or medicine at the University came to discuss testing the reliability of condoms. All the specified tests for tensile strength, ballooning and drop impact were irrelevant to actual service loading. A proposal submitted to some funding bodies for more realistic evaluations involving condoms that had been used in brothels was (unsurprisingly) not funded.

Cotterell felt that Australia was provincial when he came to Sydney in the 1960s, and in Mai’s opinion this was no different in the early 1980s. After receiving funding for one particular research program, Mai wanted to supervise a PhD student. But there was some resistance from a senior civil engineering staff member, since “fibre cements” was definitely not considered by him to be the province of mechanical engineering. Today, things have changed: many research projects are interdisciplinary.

Mai takes great pride in his postdoctoral fellows and PhD students’ achievements and successes, whether in academe or other spheres. He was very moved that many returned to a Sydney Workshop[19] and contributed to two festschriften on his sixtieth birthday in 2006.[20]

Mai has held the University Chair in Engineering since 2004. He was elected to the Royal Society (FRS) in 2008, the Royal Academy of Engineering (FREng) in 2011, the Australian Academy of Science (FAA) in 2001, and the Australian Academy of Technological Sciences and Engineering (FTSE) in 1992. He was appointed Member of the Order of Australia (AM) in 2010 for his service to engineering, particularly in the fields of advanced composites and fracture studies.

Lin Ye

After Brian Cotterell left, Lin Ye was an Alexander von Humboldt Fellow recommended to Mai by Klaus Friedrich of the Institut für VerbundwerkstoffeInstitute (IVW), Kaiserslautern. He was interviewed by Roger Tanner in France and appointed lecturer in 1992. This was a strategic appointment, for at the time advanced composites research was booming with the newly established CRC-AS, and Ye's research was on the mechanics and processing of composites structures. He had also had aeronautical engineering training at BUAA, China. Ye helped transform the CAMT into a leading international centre of excellence for advanced composites research. The CRC-AS directors, Gordon Long and Ian Mair, still allowed basic research to be done by its partners. Unfortunately, this is no longer the case today.

In the 1990s, fibre composites with thermoplastics matrices were hot research topics for reasons of recyclability, reparability, improved toughness, failure strain and rapid, low-cost, mass production. But basic understanding was lacking. Ye pioneered mechanics models for prediction of processing windows for advanced thermoplastic composites; and he developed the basic framework on fusion bonding of polymer composites structures.[21]

In the late 1990s to early 2000s, in collaborations with industry and ARC funding, Ye worked with CSR Ltd to develop wood fibre reinforced plastic products based on industry and post-consumer wastes such as wood flakes and recycled polyolefin. He also worked with Hawker de Havilland to model pultrusion process of large scale aerospace sections to bid for Airbus components manufacture; and with Pacific ESI to model and analyse thermoforming for cost-effective manufacturing of advanced composite structures.

Continuous online damage identification and reliability assessment of engineering structures require knowledge integration of informatics, sensor technology and materials engineering. Ye called this "embedded intelligence", efficient, smart health monitoring. He substantially advanced understanding of active sensor networks by using Lamb waves for identification of damage in composite laminates and beams, and in cracks in aluminium plates. These advances included: models for PZT actuators and sensors that propagate and sense guided waves; intelligent signal processing and pattern recognition techniques using wavelet transforms; forward and inverse algorithms for identification of damage; and the invention of a novel digital damage fingerprints concept to identify and assess damage quantitatively.[22]

Ye also found important engineering solutions to problems in metallic structures. Laser shock peening is an effective process used to increase the resistance of metals to crack initiation and growth due to cyclic loading and fatigue. With the support of CoE-DM, Ye developed the first comprehensive procedures to model and provide process parameters for optimisation of residual stress distributions in practical applications. [23]

In 1984, Ye was honoured with a *Friedrich Wilhelm Bessel Research Award*, awarded to a young international renowned scientist with less than eighteen years post-PhD by the Humboldt Foundation. He was promoted to Professor in 2003, became Head of School in 2004-07 and has been Director of CAMT since 2010. For his outstanding contributions to composites and to smart materials and structures for Australia's aerospace industry he was elected FTSE in 2005. In recent years, he has extended his research to nanomaterials and nanocomposites.

Liangchi Zhang

Liangchi Zhang was appointed lecturer in 1992. He had completed his PhD at Peking with Tongxi Yu, then did postdoctoral work at Cambridge with Ken Johnson and was STA fellow at MITI's National Mechanical Engineering Laboratory. He and Mai shared some common interests in nanomachining leading to their first ARC grant[24] on "ductile regime grinding of ceramics" (1994-96). They co-supervised a PhD student on nanopolishing[25] funded by a leading eye research laboratory.

Zhang played a significant role in research, teaching and service at the School and Faculty levels. He revamped the Manufacturing courses and built up a very large research group with significant ARC and industry funding. He was promoted to Professor in 2003 and served as Associate Dean and Director of the Graduate School of Engineering (2003-07). He made outstanding contributions in precision engineering from nanoscopic to macroscopic scales and from fundamentals to industrial applications. His work on nanomechanics and nanomaterials, machining technology and engineering plasticity has influenced professional practices in the Australian manufacturing industry. He has provided significant leadership in advancement of new postgraduate programs for engineering education. Zhang was elected FTSE and also awarded an Australian Professorial Fellowship in 2008. He resigned in 2009 and took up a Scientia professorship at UNSW.

Caroline A Baillie

Caroline Baillie literally burst into the School, knocking on Mai's door one hot summer day in the late 1980s, looking for a job. She was Mike Bader's PhD student at Surrey, in Australia on a work visa, and she had run out of money. She worked in Mai's laboratory and made a deep impression on everyone, particularly Jean Bennett. She was subsequently appointed as the School's first female lecturer and came to Sydney in 1992.

She taught bioengineering subjects and embarked on new research areas with natural fibre composites and biomimetics, for which she later achieved world fame. By 1996 she had built up a sizeable research group and graduated two PhDs. Her interest shifted to education development and she returned to the UK in mid-1996 to pursue this goal. Baillie is multi-talented and could have made greater impact in the School had she stayed longer. (See Figure 5) She now holds the Chair in Engineering Education at UWA.

Figure 5 *Left:* Caroline Baillie's beloved motor bike. *Right:* Baillie at a CAMT function.

Andrew J Ruys

Andrew Ruys worked with Mai as a U2000 fellow (1997-2000) on ceramics processing and functionally graded fibre-polymer biocomposites after completing a PhD with Chris Sorrell and an ARC postdoctoral fellowship at UNSW. He was later awarded an ARC QE2 fellowship (2001-05). In the early 2000s, Biomedical Engineering was one of the School's flagship programmes and was in very high demand. It needed proper coordination and a structural review. Caroline Baillie had already left and Lynne Bilston resigned in 2002. In 2003 Ruys became senior lecturer and programme coordinator. He put in tremendous efforts and long hours making Biomedical Engineering one of the best in Australia, ensuring its full accreditation by the IEAust. He was promoted to Professor in 2011.

Xiaozhou Liao

When Mai was a research-only Federation Fellow and enrolments in the materials courses were increasing, Xiaozhou Liao was appointed lecturer in 2006. Under the supervision of David Cockayne at Sydney, Liao studied the composition, morphology and deformation of semiconductor quantum dots with transmission electron microscopy techniques, obtaining his PhD in 2000. He continued his postdoctoral research in Los Alamos National Laboratory (2001-04) and became a research scientist/Associate Director of the electron microscopy core facility at Chicago (2004-06). These experiences gave him opportunities to work with some of the world's best materials scientists.

Liao quickly assembled a research team with good support from the ARC and his QE2 and Future fellowships. His work now covers severe plastic deformation on metals and bulk metallic glasses, deformation twinning in nanocrystalline metals, size effects on mechanical properties of nanowires, etc. He brought a "materials science" perspective to engineering materials research in the School and a different focus towards nanomaterials. Liao has published prolifically in high impact-factor journals. Liao has been Associate Professor since 2011.

Qing Li

Li's PhD thesis, supervised by Grant Steven at Sydney, was written on evolutionary shape and topology optimisation of structures subjected to thermal and mechanical stresses. He continued this research on topology optimisation and extended his FE studies to dental bridges during his Australian Postdoctoral Fellowship (2001-03), before becoming a Senior Lecturer at JCU (2004-06). When the Biomedical Engineering programme at the University of Sydney was attracting many more students than its academic staff could cope with, the School used the University's Sesqui funding to appoint Qing Li as Senior Lecturer in 2006.

Li's computational skills and evolutionary topology optimisation techniques have found broad applications for microstructure design of materials with tailored objectives, bone remodelling, scaffolds for tissue engineering, and mechanics of structures problems. He is highly productive and has built up a good research team around him with his ARC grants. He was promoted to Associate Professor in 2010.

Li Chang

Li Chang did his PhD on the tribological properties of polymers filled with nanoparticles with Klaus Friedrich at Institut für VerbundwerkstoffeInstitute at Kaiserslautern. He was awarded an Australian Postdoctoral Fellowship (2005-08) to investigate the use of nano-particles as lubricants. His other research interests include nanomechanics, nanomaterials and precision manufacturing. After Liangchi Zhang's departure he was appointed lecturer in 2011 and taught courses on solid mechanics and manufacturing engineering.

J. Gordon Williams

Gordon Williams is one of the world's leading researchers in fracture mechanics and advanced materials, especially polymers and composites. He was Mai's postdoctoral advisor in the mid-70s at Imperial College. He has been a visiting professor in our School since 2002, spending two to three months of every year here. His current work concerns cutting mechanics of foodstuff and plastics. He has worked with Brian Cotterell on classic fracture mechanics problems and provided insightful advice both to the CAMT on its materials and fracture activities and to young staff on research methodologies and directions. He has assisted the School in strategic planning, staff assessment and research quality evaluations.

[1] Tate, T. (1850) *On the Strength of Materials containing Various Original and Useful Formulae Specially Applied to Tubular Bridges, Wrought Iron and Cast Iron Beams, Etc*., Longman, Brown, Green, and Longmans, London.

[2] Warren, W. H. (1887) *The Strength and Elasticity of New South Wales Timbers of Commercial Value*, Govt. Printer, Sydney.

Warren, W. H. (1890) *Transverse Strength of Australian Timbers*, Turner and Henderson, Sydney.

Warren, W. H. (1892) *Australian Timbers*, Govt Printer, Sydney.

Warren, W. H. (1894) *Engineering Construction in Iron, Steel and Timber*, Longmans and Green, London.

[3] Royal Commission of Inquiry into the Alleged Defects and Unsuitability of the Baldwin Locomotives, 1892.

[4] The Kirkaldy testing machine is in the Kirkaldy Museum located in the original (specially built) Kirkaldy Testing Laboratory at 99 Southwark Rd, London.

[5] The Green and Batley testing machine is no longer operational, but was used by Cotterell in 1964 as the most convenient machine to fracture large sheets (1.8 x 1.2 m) of polymethyl methacrylate.

[6] William Ernest Dalby FRS was at Imperial College, London, from 1910 until he retired in 1931 and he designed the Testing Machine during his retirement. He died in 1936 shortly before the Testing machine was commissioned.

[7] Barraclough, H., and Gibson, W. H. H. (1938) The new Dalby straining machine with characteristic applications, *J. Inst. Engnrs. Aust*., 10:107-118.

[8] Baley, H. G. (1959) Gelatin as a photoelastic material, *Nature*, 183:157-158.

[9] The Coker Polariscope was donated to the Powerhouse Museum in the 1970s.

[10] Gibson, W. H. H., and Gilet, P. M. (1938) Transmission of torque by keys and keyways, *J. Inst. Enginrs. Aust.*, 10:393-404; 427-432.

Gilet. P. M. (1938) Apparatus for photo-elastic experiments in pure torsion, *J. Inst. Enginrs. Aust.*, 10:433-435.

[11] Mansfield, E. H. (1987) William Henry Wittrick. 29 October 1922- 2 July 1986, *Bio. Mem. Fell. Roy. Soc*., 33:710-728.

[12] Axelrad, D. R. (1959) *Strength of Materials for Engineers*, Pitman Engineering Degree Series, London.

[13] Subsequently it was shown that the placing of the thread was not as critical as first thought and the split nut could be formed much more cheaply by cold forming.

[14] Roger Tanner went to pick him up at the Sydney airport but had to wait for a few hours. There was a difference in his travel document spelt as “Mi” based on Mandarin pronunciation and his appointment letter spelt as “Mai” on Cantonese pronunciation. In fact, both “Mi” and “Mai” mean “Rice”.

[15] Bob Bilger introduced Mai to James Hardie Industries Ltd helping him to secure this funding for this R&D project. The results of this project also led to the first book of its kind on fracture mechanics of fibre cements. See Cotterell, B. and Mai, Y-W (1996) *Fracture Mechanics of Cementitious Materials,* Blackie A&P/Chapman & Hall, 294 pp.

[16] ESIS Test Protocol on “Essential Work of Fracture”, Version 5, October, 1997

[17] Chen, X. H. and Mai, Y-W (2012) *Fracture Mechanics of Electromagnetic Materials*, Imperial College Press, London, UK. Early research in this area was done by Mai, Qinghua Qin and Baolin Wang when the latter two were QE2 fellow and ARC research fellow at the School. Qin is now professor at ANU and Wang Future fellow at UNSW.

[18] Johnstone, B. (2001) Bringing the brains back home, *New Scientist*, 27, October, 57.

[19] A Workshop was held in Sydney on 23-25 January 2006. A proceedings of the Workshop on *Fracture of Materials: Moving Forwards, (Liu HY, Hu XZ and Hoffman M, eds),* was published in 2006 by Trans Tech Publications Ltd, Switzerland, 385 pp.

[20] *Modelling and Characterisation of Composites*, (Ye L, Hu XZ and Hoffman M, eds), Composites Science and Technology Special Issue honouring Prof Yiu-Wing Mai, Vol 67, No 2, 2007, pp 149-324; and *Fracture of Material: Moving Forwards*, (Hoffman M, Hu XZ and Ye L, eds), Engineering Fracture Mechanics Special Issue honouring Prof Yiu-Wing Mai, Vol 74, No 7, 2007, pp1007-1202.

[21] Ageorges, C. and Ye, L. (2002) *Fusion Bonding of Polymer Composites*, Springer Verlag, London, 273 pp. This is the first book on fusion bonding.

[22] Su, Z. and Ye, L. (2009) *Identification of Damage Using Lamb Waves: From Fundamentals to Applications*, Springer-Verlag, London, UK, 346 pp.

[23] Ding, K. and Ye, L. (2006) *Laser Shock Pinning: Performance and Process Simulation*, Woodhead Publishing, Cambridge, UK, 162 pp.

[24] L. C. Zhang and Y-W Mai, Australian Research Council Grant: "*Ductile Regime Grinding of Advanced Ceramics*" (1994-96). This grant together with funding from the University enabled them to purchase an ultra-precision grinder Minini Junior 90 CF CNC M2861.

[25] Sun, J. (1998) *Polishing of Contact Lenses and Improvement in Polishing Tool Design*, Ph D Thesis, University of Sydney.

[26] An h-index of x is defined as x papers each of which is cited at least x times. It is accepted as one measure of the impact of a researcher's published works.