Engineering Reality Magazine recently interviewed Professor Pedro Camanho from the Dept of Mechanical Engineering, University of Porto, Portugal. Pedro received his PhD in Composite Materials from the Department of Aeronautics at Imperial College in London before returning to his native Portugal to continue his research in the University of Porto over the last two decades. He is a visiting Scientist at both NASA Langley and the U.S. Air Force Research Lab, he works with MIT in Boston, the European Space Agency, Daimler AG and Airbus. He is a previous winner of the prestigious NASA H.J.E. Reid Award, is a member of the Advisory Board of the European Mechanics Society (EUROMECH) and serves on the Editorial Boards of Composites Part A (Elsevier) and Computers, Materials and Continua (Tech Science Press) Journals. His main research interests are in the structural integrity of advanced composite materials, fracture mechanics, size effects on composites, fatigue and new concepts for advanced hybrid composite materials in aerospace, variable stiffness and ultra-thin composites. He is regularly invited to present keynotes at conferences all around the world.
Natural composites have arguably been around for a long time, what do you see as the main milestones in the history of mankind’s use of composites?

PC: This is a big subject, but one could argue that the ancient Egyptians invented composites with their use of mud-and-straw bricks in the Middle East 5,000 years ago. And in Homer’s Iliad we hear of Achilles’ shield being made up of a laminated steel structure to give it strength and lightness. The Ancient Romans invented a form of concrete which has arguably been one of the most durable throughout history as we see it today in places like the roof of the Pantheon in Rome. Roman concrete was a form of composite made out of a mortar, or cement paste, that used volcanic ash with lime and seawater and then they added chunks of volcanic rock aggregate to create an incredibly strong and durable material. In the Dark Ages up through the Medieval era, shields and crossbows were made out of composite wood laminate structures for flexibility yet with great strength and durability but they were also light to carry. Humans have therefore always been inventing materials to help in their defense and construction industries!

What about the modern interest in composite materials - where did it all begin and what were the drivers?

PC: Modern interest in composites began when scientists developed plastics. Until then, natural resins derived from plants and animals were the only source of glues and binders. In the first half of the 20th Century, plastics such as vinyl, polystyrene, phenolic, and polyester were developed, and these synthetic materials outperformed single resins derived from nature. Plastics alone could not provide enough strength for many structural applications when compared with metals - reinforcement was needed to provide additional strength and rigidity. In 1935, Owens Corning introduced the first glass fiber, ‘fiberglass’. Fiberglass, when combined with a plastic polymer, created an incredibly strong structure that was also lightweight. This was the beginning of the Fiber Reinforced Polymers (FRP) industry we know today. The Second World War also drove the development of lightweight plastics for military aircraft design. However, two names continually recur in the history of modern composites – Brant Goldsworthy who was born in 1915 in California and Prof Anthony Kelly who was born in 1929 in the UK and who later went on to have a glittering career at Cambridge University. Goldsworthy is often referred to as the ‘grandfather of composites’ because he developed many new manufacturing processes and products, including the first fiberglass surfboard which revolutionized the sport. He also invented a manufacturing process known as ‘pultrusion’ that allowed dependably strong fiberglass reinforced products to be created. He set up and sold numerous companies and published hundreds of papers as well as being granted 50 patents throughout his lifetime. Today, products manufactured from his process include ladder rails, tool handles, pipes, arrow shafts, armour, train floors, and medical devices. Prof Tony Kelly throughout the 1960s and 1960s in the UK was in many ways the ‘father of composite materials’ as he set down the principles of materials science for composite materials, particularly the understanding of strength, toughness and creep of short fiber composites, and his work led the way to relating fiber reinforcement and conventional strengthening methods of metals. This was followed by the experimental analysis of fiber bundle failure. His group explored for the first time the phenomenon of multiple fracture of a fibrous composite in detail which explained the properties of fiber reinforced cements and concretes and this has led to the whole development of ceramic based composite materials as well as to an understanding of the modes of toughness of laminated composite structures with resin matrices. Finally, I must also mention the work of Professor Steve Tsai from Stanford University that resulted in seminal contributions in the field of the mechanics of composite materials, in particular to the understanding and prediction of failure.

What are the modern drivers for the adoption of composites?

PC: The main driver for the rapid adoption of composite materials in the modern world has been lightweighting in transportation and defense. The US Military embraced composites for military applications in the 1960s. Elite Sport pushed the boundaries in the 1980s and 1990s with motor sport and water sports leading the way. Lotus in Formula 1 Motor Racing were famous for pioneering their famous composite car wings. Indeed, many racket sports were some of the earliest applications of composites visible to the general public because of

![Figure 1](https://mscsoftware.com)
lightweighting and strength benefits. And now with the demands of sustainability in the modern world and concerns over CO₂ emissions in transport, composites are being adopted widely in the aerospace industry to make aircraft lighter and fit in the same tank of fuel. This leads to a lower carbon footprint for each aircraft. The Airbus A350 in Europe is leading the way with its adoption of composites. About 53% of its structure is composites including most of the wings and fuselage including the center wing box, keel beam, tail cone, skin panels, frames, stringers and doublers, as well as passenger and cargo doors which is an amazing percentage these days (3).

This is mainly due to CFRP, Carbon Fiber Reinforced Plastic and GFRP, Glass Fiber Reinforced Plastic. In the chemical process industries too, we are seeing demands for overwrapped pressure vessels made from composites.

Tell us more about the challenges of composites to solve them from your perspective?

PC: Sustainability is I think about the mix of sociology related to why we humans change our behavior coupled to science and technology to make the changes that we know we need to make to allow our planet to survive in a form our children and grandchildren can survive in. Composites have both pros and cons in the sustainability arena. They allow us to do lightweighting which saves on carbon emissions directly in transportation applications, but they use chemicals in their manufacturing processes that can have a deleterious environmental impact. They also have poor biodegradability over time. Surf boards are perhaps the cheapest composites you can buy today. They use epoxy resins with glass fibers as a cheap strengthening material whereas thermoplastics used in combination with thermostet resins for more industrial applications. There is research into more ecological materials in the design of aircraft (3). These include biodegradable biological fiber composites for interior surfaces of aircraft bio-based resins, recycled carbon fibers, sandwich cores, hybrid reinforcements and electrical conducive tougheners.

The automotive industry has been slow to adopt composites in their products because of the cost/production challenge. It is hard to get mass production of auto composites with the consistency of grade right to satisfy the auto industry’s needs at a cost point that makes sense to them. Again, the drive towards electrical vehicles (with their heavier batteries and cable & harness systems) is a factor militating towards a move to more lightweight materials. And with environmental legislation restrictions and penalties related to CO₂ emissions coming into force here in Europe in early 2020, this is also a vector towards the use of more composites in vehicles. Generally, America is behind Europe in its sensitivity towards environmental issues, but even in the US auto industry they are projecting a move away from the Car Fleet using mild steel to an assortment of metallic and non-metallic materials in future as shown in the graph below.

I believe that engineering simulation software techniques can be one of the keys to developing new sustainability solutions for composites because it is relatively cheap, safe to test your hypotheses, and quick to test many different options. In our area of laminated composites for aircraft design, model functionality has been developed in response to the demand for sustainability related to the growing trend towards reducing the weight of parts that require more reliable computer simulations for failure prediction of composites.

Tell us more about the challenges of Laminated Composites for Aircraft?

PC: Laminated composites have important and irreplaceable applications in modern aircraft structures because they have extraordinary properties like high strength, stiffness, and light weight. Nevertheless, a serious obstacle to more widespread use of these materials is their sensitivity to impact loads. This is what my research work has investigated over the years because laminated composites fail in a complex way. There are two ways of examining failure; by physical testing, that is a ‘Building Block’ test, or by Finite Element Analysis models but as with all computational models, good physics models need to be used in the software. That is where my team and my research have a part to play.

If we look at Physical Testing first, usually what happens is that a simple block of material under test called a ‘Coupon’ is used as a test specimen and elastic properties, strength and fracture toughness are measured. Furthermore, complex physical test scenarios can be applied to the material in terms of crash tests, lightning strikes, bird strikes etc. Normally a large statistical basis is required to measure the A- or B-basis allowables, which are of critical importance for the safe design of composite aerostructures. Usually composites have much better cycling behaviors than metals but in terms of lifecycle fatigue it is extremely difficult to simulate today. It is still one of the biggest industry challenges today for aerospace to develop models for lifecycle fatigue.

Virtual Testing of composites started in FEA codes back in the early 2000s and that was a very positive evolution for the aerospace industry in my view. But computational models are only really as good as the physics models underlying them. That is why software like Digimat is starting to use my team’s research models in their predictive simulations which ultimately leads to virtual certification through ICME (Integrated Computational Materials Engineering) multiphysics simulation approaches. Metals have ASTM standards for testing; complex materials are different, hence the need for virtual standards and the need for models to develop test methodologies for composites.
How do you use Digimat in the design of composites and what is your liaison with the e-Xstream organization?

PC: I have worked with Dr. Roger Assaker and the e-Xstream team in Belgium over the years and their recent product release, Digimat 2019.1, now implements our Progressive Damage Analysis model (4) making it possible for engineers to comprehensively model how material choices affect the failure of Continuous Fiber Reinforced Plastics (CFRP) from coupon to manufactured panel and thus improve the accuracy of composite allowables with the modeling of defects in Digimat-FE with its microstructure simulations. The effect of defects such as porosity, out-of-plane undulation, and disbonds in determining safety factors and appropriate tolerances can be examined (see figure below). Our models therefore help in the design of fiber reinforced composites in terms of understanding the safety limits of lightweighting. Hence, Virtual Testing can complement Physical Test campaigns to help in saving costs and optimizing materials if used early in a design process so that the failure envelope of a material can be computed in a virtual test lab. I like the way that the evolution of the Digimat product shares our vision of applying advanced computational models coupled with material development. Things like length scales and uncertainties in simulation need to be taken care of in modern simulation techniques. We use Digimat for additive manufacturing projects in our lab in Portugal. It allows us to look at thermoplastic composites so we can develop and patent new materials for emerging applications.

What do you foresee coming in the future for composites and their evolution into exciting new applications?

PC: The future is exciting for sure for composites, and many new opportunities are knocking at the door. I see multifunctional structures appearing in the near term. For instance, I believe we will see safe “Structural Batteries” where the battery for an electrical or hybrid vehicle is wrapped around the shape of the chassis or fuselage rather than a monolithic box like we have today. Similarly, I foresee “Structural Health Monitoring” coming along based on self-sensory materials that will identify the severity of damage going on in the host. In the aerospace industry I see morphing of wings coming along to be more fuel efficient – that is an application that will be ideal for composite materials with multiple buckling struts. I see computational modeling accelerating in this sector because we still have to do more and better non-linear multiphysics and multiscale analyses to virtually understand and test ideas. There is an ongoing project at MIT in Cambridge to embed carbon nanotubes into composites to deice wings by applying an electric current through the highly electrically conductive carbon nanotube structures thus avoiding other techniques used today that can be time consuming and expensive. Finally, I believe that material design and performance will go hand in hand with structural design. My vision would be to optimize microstructures to affect final structural performance of an aerospace part or assembly at the conceptual design stage. I can even envisage more artificial intelligence (AI) coming into engineering simulations to make design space exploration of composites easier for engineers. Techniques like Reduced Order Models (ROM) will become more commonplace for well-defined FEA problems so as to speed up millions of design simulations especially as cloud deployment becomes ever easier.

References

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