Composite testing gets smarter

Artificial intelligence is the future of non-destructive testing

Collaborating researchers from the University of Cambridge, Fuzhou University, the Rutherford Appleton Laboratory and the University of Hull have reviewed the state of the art in non-destructive testing (NDT) of composite materials. Their comprehensive and fascinating review has been published in a recent issue of *Advances in Mechanical Engineering*: ‘Non-destructive testing and evaluation of composite materials/structures: A state-of-the-art review’, https://doi.org/10.1177/1687814020913761.

In their review, they define the current challenges associated with NDT of composites and point to future research, research driven by intelligent and automated inspection systems.

We spoke to the team about their review, their current work and how they see this field developing.

**More than the sum of its parts**

A composite material is a three-dimensional combination of at least two chemically or physically different materials, with the composite displaying superior properties to those of its constituent parts. Bing Wang, of the University of Cambridge in the UK, one of the
authors of the review, explained this in more detail: ‘From a mechanical perspective, composite materials are usually composed of two phases: a reinforcement [phase one], said Wang, ‘which is embedded in a softer constituent, known as the matrix [phase two]’. Generally, the reinforcement is in the form of a fibre, a fabric or particulate, and the matrix is a metal, a ceramic or a polymer. While, traditionally, the reinforcement will increase, for example, the material’s strength or stiffness (hence the term reinforcement), other advantages or properties can be bestowed, such as reduced weight, corrosion resistance, faster assembly, improved damping and so on. However, as Wang notes, ‘in particular, there is considerable scope for tailoring their structures to suit various conditions. Therefore, they have been used in a wide variety of applications, especially for aerospace, transportation, construction and medical equipment’.

While composite materials have obvious benefits, they do have disadvantages, mostly associated with difficulties in their manufacture.

The parts can be difficult
These difficulties are usually associated with generation of residual stresses in manufacture, stresses that can be induced through several mechanisms. While such stresses can be, incidentally, beneficial (for producing morphing composite structures, for example), they are usually detrimental to the material’s performance.

‘Manufacturing of composite materials is a multi-variable task, usually involving many procedures, where various forms of flaws and defects can occur within a composite product and act as stress concentration points’, explained Wang, and ‘although they may be avoided or removed by careful design and processing, thermal residual stresses are usually inherent in composite processing and therefore are difficult to avoid’.

Thermal residual stresses are caused by mismatches in thermal expansion coefficients between constituents, and these discrepancies can lead to substantial errors during curing, such as warping, buckling and cracking (and crack propagation) and delamination. ‘These flaws’, said Wang, ‘combined with others, can greatly reduce the effective strength, stiffness, and service time of a composite product’.

In service
Composite materials are employed in a wide variety of industries, but perhaps their canonical application is in aerospace industry. And this presents an additional challenge to composites.

Wang told us that ‘their manufacturing procedures are rigorously controlled ... [but] when in service, damage caused by impact can often be a critical threat to structural integrity’. For obvious reasons, regular inspections are necessary for materials employed in this industry, and NDT becomes paramount.

The structural health, efficiency and safety of aerospace materials are generally monitored through infrared thermography and ultrasonic techniques. However, as the team have explained in their paper, composite materials represent a singular challenge when it comes to NDT.

Almost too complex
Composite materials are usually (almost necessarily) non-homogeneous and anisotropic. ‘This means’, explained Wang, ‘that defects and damage can occur within numerous locations at various levels of scale, making it difficult to track all damage sites, leading to complex damage mechanisms: [accumulations of] multiscale rupture mechanisms that include matrix cracking, fibre/matrix debonding, fibre fracture and pull-out, micro-buckling, waviness, and delamination’.

The complex nature of these failures means that a single NDT method would struggle to recognise and distinguish their nature. Furthermore, said Wang, ‘Available NDT methods also suffer from inabilities to cover large areas of composite structures to provide efficient and reliable detection, as well as offering efficient scanning of composites with complex geometries’.

So, how are we to overcome these rapidly multiplying problems? The answer, the team believes, lies in artificial intelligence (AI).
Intelligent testing

In Table 9 of their review, Wang’s team summarised the challenges associated with each NDT technique in the field of composite materials. As we have briefly discussed here, these problems are extremely self-consistent and complex.

This is where AI comes in: ‘The most imminent solutions to the challenges as we summarised in Table 9 would be the implementation of artificial intelligence in data processing and pattern recognition processes in the NDT techniques, as these are usually time-consuming (dependent on computing power and algorithms) and require highly experienced technicians. These can be achieved through artificial neural network coding or algorithms to enable automatic detection and recognition of defects/damage without human error. In academic research, there are growing publications in these areas, and we believe their implementation within composite industries is fast approaching’.

The future

Bing Wang and collaborators are driven by their passion for the field of morphing composite structures, including those with bistable or multistable shape-changing properties. ‘Novel lightweight morphing structures and applications for aerospace, wind turbine, and transportation are also my major interest’, said Wang. A full-composite aircraft fuselage can have a service life exceeding 20 years, so the durability of shape-changing structures operating under large displacements is more crucial than ever. To this end, Wang said, ‘I look forward to a continuing collaboration with our co-author team to tackle the multiscale challenges, and the various NDT techniques are an inherent part of this field. I am also excited by the development of green composites, since recycling of glass fibre or carbon fibre reinforced composites are problematic. I would like to devote my career to green morphing composite structures, as a contribution to aiming for a sustainable future’.

As these materials become more and more advanced, more and more exotic, the importance grows of similarly advanced – and exotic – NDT technologies. With groups like Wang’s and his collaborators’, the future is exciting; ‘Adopting novel technologies will offer great potential for NDT techniques; e.g. the terahertz-based NDT method has already demonstrated its advantages in terms of penetration depth. Free electron lasers and modern spallation sources are promising techniques and on-going for the next generation synchrotron X-ray and neutron facilities to offer further advanced capabilities’.

The team behind the review

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Further reading

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