FEATURE

Multiscale composites

Laurie Winkless and Soraia Pimenta*

Reinforced Plastics spoke to Dr Soraia Pimenta about a new area of composites multi-scale discontinuous composites, and how they can serve both the high-performance and short-fiber composite markets.Soraia Pimenta.

Dr Pimenta, could you tell us about your background, and what led you to composites research?

I'm a research fellow in the Department of Mechanical Engineering at Imperial College; I joined the department about one year ago, and before that I graduated as a mechanical engineer in Portugal, coming to Imperial to do my PhD, which focused on recycled composites.

At the moment my research group is still working on composites, but addressing a broader range of topics, including understanding how composites break, developing models to be used in designing structures with composites, and also developing and supporting the development of new improved composites, either directed to industry or to follow a more blue skies approach, by looking for inspiration from nature.

Can you tell us more about these multi-scale discontinuous composites (MDCs) that you work with? What is so special about them, and how do they compare to the kind of high-performance composites, or short-fiber composites with glass fibers?

Multi-scale discontinuous composites bring together the advantages of the two types of composites that you have just mentioned; the very high-performance composites made with aligned carbon fibers and manufactured in a very structured way, and the lower range of short-fiber composites typically manufactured with glass fibers, which are less stiff and less strong. Multi-scale discontinuous composites try to combine the advantages of these two types of composite, and we call them multi-scale discontinuous composites because the *multi-scale* aspect is very important in achieving this balance between their properties and their manufacturing costs. So what we have is a material that is discontinuous, so the fibers are short. But instead of having the fibers randomly

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dispersed in the matrix, we actually have the fibers aligned and well-compacted into bundles, and those bundles are the discontinuous element that we want to reinforce our matrix. So we basically have two levels of reinforcement here: we have the bundles reinforcing the matrix, but the bundles themselves are composed of thousands of carbon fibers, all aligned in the same direction, and this architecture allows you to pack more fibers into the composite, so you are able to achieve a high-volume fraction of fibers in your composite, which makes the mechanical properties immediately higher; and on the other hand, because they are discontinuous, you can manufacture them in much more efficient ways than you can for conventional continuous materials. So basically, you combine the high performance of carbon fibers with the manufacturability of discontinuous composites.

How do you actually produce these MDCs? Can you mold them into shapes?

Yes, there are several ways to manufacture parts with these composites, but the main idea is that you take small bundles with thousands of fibers inside them, and you put those in a mold. You add some resin, and then use a compression molding process. So whatever 3D shape you had in your mold, you will get the same 3D shape in your final component, without any need to manually try and find out the best way to cut a conventional composite, which is typically a 2D object converted to a complex 3D shape. So using these materials avoids lots of trouble in the manufacturing process, and actually allows you to mold the material in whatever 3D shape you ultimately require. Because they have this discontinuous structure, they don't have the kind of directionality issues that aligned carbon fibers have, providing more flexibility on how they are used.

In terms of the wider composites' landscape, why are they so useful right now? And why is this a timely area to be involved in?

Discontinuous composites have been around for a very long time, but the interest in this type of very high-performance, discontinuous composite, has really only *kicked off* in the last few years. I think one of the main reasons for this is that the automotive industry is really looking to reduce the weight of cars by replacing some of the heavier materials with carbon fiber composites. The problem is that the automotive industry needs to manufacture parts in a matter of minutes, and the methods that we have been using for manufacturing high-performance conventional composites take hours, and can even take a day. For the automotive industry, this is of course not good enough. So there is now a huge drive towards trying to incorporate composites in the automotive industry, and these type of high-performance discontinuous composites which can be molded in a matter of minutes is very suitable for automotive applications.

Does that mean that, if we get to the stage at which we understand their performance very well, they could potentially replace steel or aluminium in an automotive environment?

At the moment, carbon fiber composites are already replacing metals in very high-end cars, so of course Formula One is one

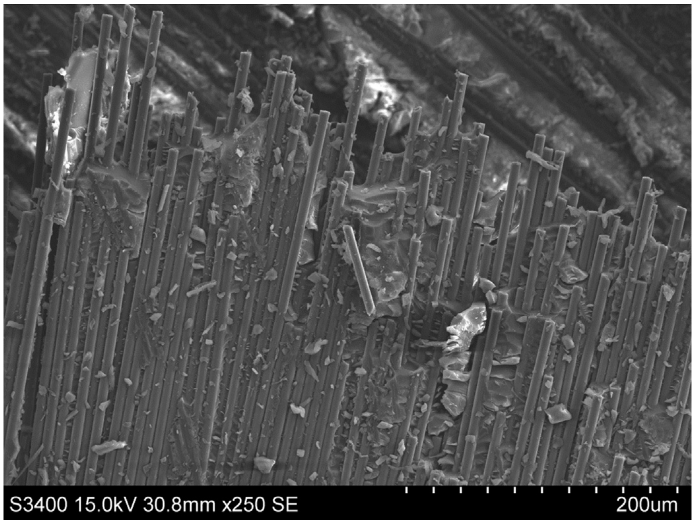
One day soon, MDCs could be used in street cars, for more power and lower fuel consumption. Image licensed by Shutterstock.

of the best examples (although that probably doesn't apply to most cars that people use). The reason for that is that the material is lighter, and therefore you have more power for your car. I believe that we will get to the point where carbon fiber composites will replace, in some components, but not everywhere, the materials used in regular street cars, and this will be extremely beneficial, because it will allow us not only to save money on fuel, but also to reduce CO_2 emissions significantly.

Given that the fibres are arranged in bundles, which are fairly randomly oriented through the matrix, predicting their behavior must be a challenge. Is that something you are addressing in your work on how composites break?

Precisely, we are focusing on understanding how these materials break, and how we can design components with them; not using trial and error, but using computer models that can tell us if the material is going to sustain the load that it is required to. So this, of course, involves first actually doing experiments with the materials, and then taking a look at the fracture surfaces, seeing

Analysing failure in tow-based discontinuous carbon-fibre composites: measuring the fracture toughness during crack propagation.

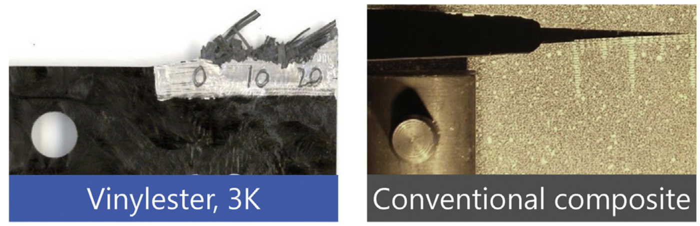


Scanning-electron microscopy of the fracture surface of a multiscale discontinuous composite, showing individual fibres tightly packed in a bundle.

if we can understand the ways in which the composites broke, and asking: Do the fibers in the bundles actually break? Do the bundles simply separate from each other? What is actually happening? Once we have that understanding, then we can actually start developing mathematical models that can be implemented in a piece of software that can be used by engineers and designers in order to actually define the thicknesses and the shapes of the components that can be produced from these materials. This is the theme of the Royal Academy of Engineering Research Fellowship that I was recently awarded: the main goal is that, at the end of these five years, we will actually be able to use computer models in order to design components with multi-scale discontinuous composites with confidence, without having to use a trial and error approach.

Will this help save costs? I would imagine a trial and error approach is an expensive way to go about designing new materials?

Yes, exactly. There will be an initial phase of experimental work, where we will go to the lab and we'll break composites, and we will



Fracture surface of tow-based discontinuous carbon-fibre composites vs conventional (continuous-fibre) composites: the failure surface of discontinuous composites shows large bundles being pulled-out and broken – meaning that these materials can absorb a large amount of energy as they fail.

see what actually happens, but in a later stage, what we want to do is to get that understanding, and to use that to develop methods so that people can design components which make full use of the mechanical properties of these materials. For instance, it's now a conventional approach with metallic components – you don't just make up a configuration, manufacture it and test it – you can do all of that in the computer with conventional materials, and that really allows you to save money; both in terms of manufacturing, and in terms of equipment, but also in terms of people's time, and what we would like to do is to achieve the same situation with this new type of composite.

Finally, are there any other novel areas you think our readers should look out for?

Yes, I think that one area that is gaining momentum, and is also something I'm very interested in, is biomimetics. We are just now starting to realize that we have a huge amount of materials which were developed not in the last ten years, not in the last hundred years, but that were developed through millions of years through evolution. If you think about materials such as bone, seashells, even wood, these materials have very interesting mechanical performances. They also have multi-functional properties, so they really provide a template for developing new materials that haven't even be considered yet – using inspiration from what nature has been able to achieve is one very exciting topic. So I'm really interested in the mechanical properties of some of these composites: the range of properties that they exhibit is very broad, providing a basis for the development of new and better materials.