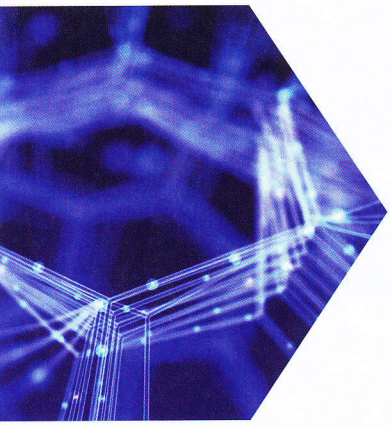

Doubts cast on graphene strength claims

The claim that graphene is 200 times stronger than steel is widely repeated. University of Cambridge Professor Harry Bhadeshia set the record straight at a London Materials Society lecture held at the Royal School of Mines. James Perkins reports.

Steel expert Harry Bhadeshia is flattered that the material he has spent his professional life researching is held in such a high regard that it is the substance against which everything else is measured. But the claim that graphene is 100 (or 200, or 300) times stronger than steel is 'absolute rubbish', according to the University of Cambridge metallurgist. The claim, which stems from research conducted in 2008, is repeated *ad nauseum* in reportage of graphene, encouraged by many university media departments.

This comparison is based on shaky foundations and, as Bhadeshia says, design involves a combination of parameters depending on the application. 'It is nonsense to talk about the dimension of a new material on the basis of just one property. A design problem is not interesting at all unless there are many solutions for the same parameters. If you are talking just about strength, it is a very boring problem to work on.'

How strong is graphene?

In 2008, researchers from the engineering department at Columbia University, USA conducted the first strength test on graphene and published the results in *Science* in a paper called *Measurement of the Elastic Properties and Intrinsic Strength of Monolayer Graphene*. The team placed pristine graphene flakes over small circular holes etched in silicon and tested their strength using nanoindentation, which involved pushing on the centre of each flake with a diamond-tipped atomic force microscope with a radius of 20nm. The studies found that the intrinsic strength of the material was 130GPa. In a quote published with the associated press release, Professor James Hone said, 'Our research establishes graphene as the strongest material ever measured, some 200 times stronger than structural steel.' The same team, in a 2013 *Science* paper titled *High-Strength Chemical-Vapor–Deposited Graphene and Grain Boundaries*, again used nanoindentation to prove CVD-grown graphene had a tensile strength of 118GPa.

A paper published in *Nanoscale* in August 2015, *Nanoindentation cannot accurately predict the tensile strength of graphene or other 2D materials*, casts some doubt on whether the results from this method are accurate but, even using the measurements from 2008 and 2013, Bhadeshia shot down the claim that graphene is 200 times stronger than steel.

The steel comparison

By comparing the strength of graphene to A36 structural steel, for example, which has an ultimate tensile strength of 400MPa, graphene is 325 times stronger than steel, but Bhadeshia explained that comparisons such as this are not acurate.

A fairer test would be against the iron whisker Brenner grew in 1956, in which he found an ultimate tensile strength of 13GPa. In theory, Bhadeshia said, it should be possible to achieve an ultimate tensile strength of 21GPa in an ideal crystal of iron. 'Divide 130 by 21 and that is only 6.19 times the strength of steel, not 100 times the strength of steel. Of course, this is the intrinsic strength of graphene, which means if I make it bigger than one micrometre, it is going to collapse. Steel I can make very, very big.'

Like for like

To compare the strength of a nanomaterial with another that has proved itself as one of the most useful bulk materials created by the human race is unfair on a number of fronts.

As Bhadeshia explained, 'The thing to notice is the strength collapses when you scale the particle by micrometers, and even nanometers. As soon as you scale the particle up, the strength collapses, and that is because the probability of finding a defect in a sample increases as the particle size is larger. This was a very well established fact in 1956.'

Other stresses a material needs to stand up to include fatigue, compression, torsion in phase, axial loading and centripetal forces. It also needs to fail in a safe, and predictable way. 'Anyone who tells you that they have created a new material because it is very strong is really talking nonsense and we shouldn't be saying this kind of thing to students,' said Bhadeshia.

Graphene is still great

Just because the claim of graphene's strength is dubious, does not mean it is not an impressive material with fantastic properties. Bhadeshia said, 'I am 100% sure we should work on it and it should be heavily funded for research. To claim things that are not true is what I am against.'

The University of Manchester is a proponent of the 200-times stronger than steel claim and *Materials World* approached the university for comment.

'The strength of a material is determined by how firmly two atoms are bound together. Carbon atoms have a high level of electrical attraction which gives graphene its strength,' a spokesman said.

'The University of Manchester has described graphene as 200 times stronger than steel based on the intrinsic properties of mono-layer single-crystals rather than their performance in devices or composite materials.'

What do you think about the comparison of graphene's strength compared to steel? Email **materials.world@iom3.org**, or tweet us **@materialsworld**

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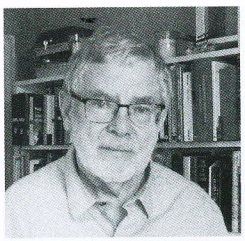
Welcome

During the press cycle of this nanotechnology-themed issue of *Materials World*, I attended a lecture by steel expert Sir Harry Bhadeshia at the Royal School of Mines in London, organised by the London Materials Society, titled *Hundred times stronger than steel*. John Oliver would have been proud of the way the Cambridge Professor took down the claims made about graphene's strength compared to steel (read the story on page 20). The lecture was a timely reminder of the care that needs to be taken when reporting on nanotechnology. The potential in this area of materials science is incredible, without exaggeration. As Bhadeshia said, 'I am 100% sure we should work on [graphene], and it should be heavily funded research, but claiming things that are not true is what I am against'. It is easy for the average person to get excited about something being 100 times stronger than steel, and it makes a great headline, which could be why this is being propagated by some universities. But is misleading the public the right thing to do? The concept of graphene is hard enough to understand without confusing people by making erroneous comparisons. I would like to think this issue of *Materials World* delivers a sober analysis of nanoscience, covering applications as diverse as water filtration membranes (page 34), functionalised plastic additives and conductive inks (page 38) and in healthcare technology (page 42). On page 15, Simon Frost writes about the potential for strengthening metals by stretching them at the nanoscale. Director of the Cambridge Graphene Centre, Professor Andrea Ferrari, also sat down with *Materials World*, ahead of delivering the inaugural Cafe Nano lecture, to talk about graphene. To view the interview, visit **app.materialsworld.org**. Finally, our coverage of the UK steel industry crisis in the November issue generated the most feedback from our readers that I have seen in my time at this magazine, so thank you to all those who took the time to write in. We value your thoughts and opinions on what appears in *Materials World*.

James Perkins, Editor

This month's contributors



Fred Starr recollects the first time he was lied to about nuclear power and the corrosion that affected the Magnox plants, on **page 31**.

Electroforming is a process that has gone unrecognised, says **Tony Hart** on **page 32**, despite its use increasing over the past 100 years.

Mines are susceptible to various forms of theft and fraud. On **page 44**, **Guy Richards** explores the various threats and countermeasures.

Front cover: Silicon wafer. Shutterstock.