

Virtual testing: materials measurement for the future

Dr Nick McCormick

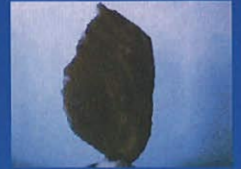
NPL

>> *"NPL will probably deal with simulations and virtual testing more and more, rather than physical testing. Also, the physical testing that's done will probably be devoted to providing input data for simulations and virtual testing."*

The Past: the dawn of technology

◆ Why do we need material properties?

- We don't, if we are in the stone age!
- If a stone flakes satisfactorily then we use it, otherwise we discard it and try another
- However, experience would teach us the difference between good and bad materials



A 250,000 year old stone tool from the Clactonian Culture

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If we are going to talk about the future, we really have to put materials measurement in its context. So I will give a brief overview of materials measurement in the past, in the present and then leading on to the future, where we think perhaps it might go.

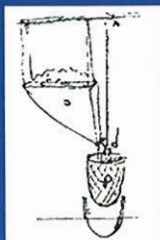
Let's go really a long way back into the past and go to the dawn of technology. If we consider stone age technology we don't really need material properties. We find a bit of stone, we pick it up, we knock it and something flies off. However, although we obviously have a little bit of experience in choosing stone, the material isn't consistent enough to make materials testing worthwhile.

So, we have to fast forward now, still in the past, to the 15th century until we reach Leonardo da Vinci who was one of the first people to invent a mechanical test machine. Now we have the concept of a specimen. Of course, the reason we can actually have a specimen is because the materials are now sufficiently uniform that the specimen will now be representative of the whole. Strength testing was invented and other tests soon followed.

The Past: 15th Century

◆ The concept of the specimen

- Materials are now being made which are sufficiently uniform that a specimen will be representative of the whole
- Strength testing machines invented, other tests soon follow



one of the first mechanical testmachines, attributed to Leonardo da Vinci



It wasn't really until the 19th century when materials were widely used on an industrial scale that testing became very important. It was people like Kirkaldy who invented, if you like, materials testing laboratories. And in particular, when people started to try to use materials, for more elaborate designs, they really pushed the envelope with materials design. There were calamities, the Tay Bridge disaster for example, and at that point, people began to realise that they needed to understand the structure and obviously needed material properties for this. It was also around about this time that the concept of a quality mark or a test marker was developed - again by Kirkaldy. I think that's worth bearing in mind for the future.

The Present: Mechanical Testing

- ◆ Materials are still mechanically tested to obtain their properties which are required for component design
- ◆ But the era of simulation is beginning
 - Some material properties can be predicted by simulation
 - Virtual testing is becoming a reality



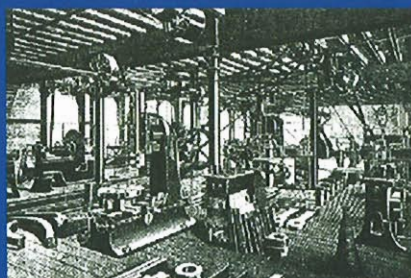
An indentation based edge flaking test, to determine fracture toughness



The Past: 19th Century

◆ Industrial Revolution

- Materials made on an industrial scale
- Widespread testing



David Kirkaldy's mechanical testing laboratory 1865



Let's move on to the modern day. Obviously we still do real physical testing to obtain properties of materials, since we need this for component design. For example, we might want to do some kind of indentation test, to measure the fracture energy or something like that. But now we can use computers and simulation, and it is getting to the point where material properties, predicted by simulation and virtual testing, is in fact becoming a reality.

Conventional and Virtual Manufacturing approach to production

The diagram illustrates the flow from an initial idea to production, comparing conventional and virtual manufacturing approaches. A large green oval represents the overall process. On the left, a red arrow labeled 'Idea' points to a green circle labeled 'Design'. Above 'Design' is a green box labeled 'Design Rules', and below it is a green box labeled 'CAD/CAM'. A red line connects 'Design Rules' to 'Design' and 'Design' to 'CAD/CAM'. A red arrow points from 'CAD/CAM' to the right, labeled 'Time/Cost' at the bottom. The right side of the green oval is a yellow area labeled 'Virtual Testing' at the top. Inside this yellow area are several ovals: 'Reliability Simulation', 'Component Simulation', 'Disposal Simulation', 'Servicing Simulation', 'Production Simulation', and a central green oval labeled 'Virtual Prototype'. Below the yellow area is a green oval labeled 'Customer approval'. A red arrow points from the 'Virtual Testing' area to the right, labeled 'Production' at the bottom.

Idea

Design

Design Rules

CAD/CAM

Virtual Testing

Reliability Simulation

Component Simulation

Disposal Simulation

Servicing Simulation

Production Simulation

Virtual Prototype

Customer approval

Virtual Manufacturing

Time/Cost

Production

But first we really have to define what we mean by virtual testing. We have defined it as a combination of high quality models, high performance computing and a user-friendly interface. All of these things are important because, for example, we can replicate the many aspects of physical testing that we are familiar with at the moment and it means that the engineers can easily use these virtual tests. They do not have to learn a new vocabulary since they can easily understand what is going on. We can also use virtual testing to derive material properties from perhaps more fundamental properties and that allows somebody who is designing new materials to be much more inventive. But of course, virtual testing is more than just simulation. The important thing is that it includes extensive validation and testing, resulting in a reliable replacement for physical testing. Professor Kelly mentioned this and I will come back to it later.

What are the benefits of virtual testing? Obviously, it is faster. Computing now allows you to reduce things like lead times in your manufacturing. It also increases what is called your manufacturing agility - your ability to take on different product lines. It's cheaper. We don't need small batches of materials - specimens can be very expensive to make and test. And also, rigorous optimisation is possible. We can look to all sorts of different variations in material properties and look at the effect that they would actually have on the materials design.

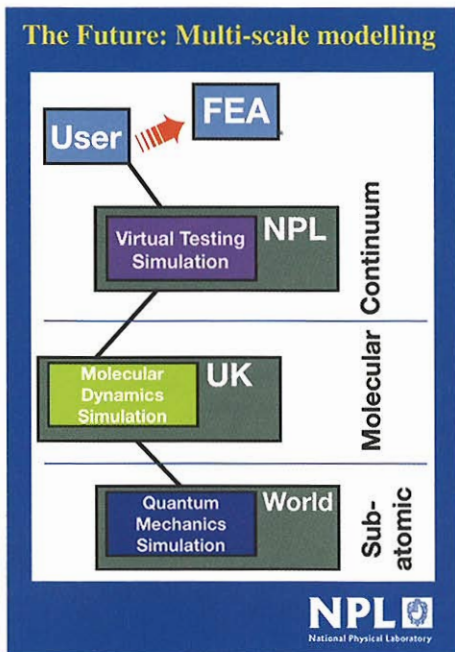
We are now going to talk about what we are doing at NPL. We have developed a virtual testing demonstrator and the area we have concentrated on is composite laminate testing using computers. We have a lot of experience in this area. There has been a lot of work on composite modelling by Neil McCartney, in collaboration with NPL's Centre for Mathematics and Scientific Computing, who have developed numerical methods of solving the relevant systems of equations. Such solutions have made great use of algorithms developed many years ago at NPL by Jim Wilkinson and others. The system we have tests composite laminate test pieces and actually simulates the damage caused as you load it and it starts to crack. That's when the material property starts to degrade. If you are designing an aircraft wing or something like that, this is an important thing that you need to know.

Our website <http://materials.npl.co.uk> has a laminate damage simulation demonstrator where you can see the kind of things that we are doing. We use a 3D model because we are looking at a 3D object and it makes it easier to visualise what's going on. We can load it, we can actually produce cracks and we can pull out layers so that we can see them in more detail. Of course, not only do we have a visualisation, we also have real time calculations and in this case, the calculations are on a server at NPL. Basically, we have a client PC connected over the Internet to the server. That sends back the smallest amount of information which is just the material properties. These fundamental properties for the simulation go back to the server which does the calculation and sends back some data and updates the 3D model. By using this kind of paradigm for operating over the Internet, we minimise the amount of information being sent and we make the systems as interactive as possible.

Now, I am now going to talk about the future - the era of simulation. One thing that is becoming very important is virtual manufacturing. Let us consider a very stylised view of what manufacturing is like at the moment. We have a design, we produce a prototype and there is test and redesign *et cetera*. So, what is going to happen in the future? We are going to have a virtual manufacturing approach. You can see in the diagram that we have amalgamated everything into one virtual process, all done on a computer, as simulation.

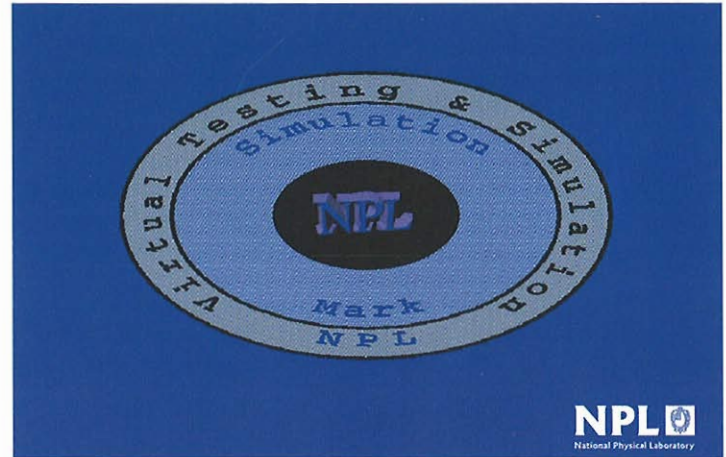
And we have things like a virtual prototype, which is at the centre of the simulation or system and then there are simulations around that, doing different things. We might look at a component, simulate it and look at how we produce it. In fact, we can even look at things like servicing, reliability and even disposal. So you can actually do cradle to grave design, there and then on your computer. We don't have to do all this kind of make and break testing. But, of course, behind all these simulations, we need materials properties, and for that, we need virtual testing that gives us property data that enables us to do these simulations.

Now, something else we might want to do in the future is hybrid mechanical/virtual testing. In this case, a few simple mechanical tests are required - we will never ditch mechanical testing completely - to provide some fundamental properties to enable virtual testing to predict many other properties of the material. We would then use them in the design process. Of course, considering the Internet, there is no requirement for mechanical testing machines and simulation systems to be geographically collocated.



Now if we think a little bit further into the future. At the moment, we are talking about the user interacting with this virtual testing simulation at NPL. This is a sort of continuum kind of simulation. But in fact, there are material properties that we need for our simulation that we, at the moment, measure experimentally and could perhaps be derived using some kind of molecular dynamic simulation. This may not necessarily be at NPL.

It could be anywhere in the UK or the world. The simulation at a molecular level might predict, for example, fracture toughness or something like that. But this in itself might well actually require some kind of quantum mechanical calculation. So again, that would require parameters from a deeper simulation. Each nested simulation would send back information further up through the system, back up to the user, who would then eventually use it in some kind of design, such as a finite-element analysis. But the important thing is that it is completely transparent to users and that they are unaware of all of these layers of simulations.



Where does NPL fit into this grand scheme? As I have mentioned and, I think, Professor Kelly mentioned earlier, NPL will probably deal with simulations and virtual testing more and more, rather than physical testing. Also, the physical testing that's done will probably be devoted to providing input data for simulations and virtual testing. But no matter how sophisticated the models, 'garbage in' will result in 'garbage out'. And, perhaps even worse, you may use good data and still get 'garbage out' because the model has not been properly tested and validated. Therefore, I think validation, testing and sensitivity analysis is vital if simulation is to obtain virtual testing status. And the kind of question that I would leave you with relates to what NPL should be doing. Maybe we should be the body who can actually produce a 21st century equivalent of Kirkaldy's testing mark, a simulation mark guaranteeing the quality of the virtual testing. «

Sir John Rowlinson (chairman)

Thank you Dr McCormick for a possible glimpse of all our futures.

The National Physical Laboratory obviously is centred around physics but we are to hear now from Dr Martin Milton about its involvement in a rather different area, one which is obviously going to become increasingly more important, that of biotechnology and chemistry.