CSEM's

Materials Monthly

May 2005 Making materials matter

Full metal jacket

Developing a future for fibre-metal laminates

Fibre-metal laminates are made by sandwiching layers of fibre composite between sheets of metal. Two different composites are shown below: Twintex (the light material) and Curv (the dark material).

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THE AUSTRALIAN NATIONAL UNIVERSITY

Luke Mosse holds up two test stampings of sheets made from different fibre-metal laminates. Both failed in different ways. The FML using Curv cracked, whereas the FML using Twintex crumpled.

Here's a great idea: why not combine sheets of metal with sheets of polymer fibre to generate a composite that has the fabulous strength of metal combined with the capacity to resist failure from cracking? Well, like many good ideas, it's been done. However, because it costs a bit more to produce these fibre-metal laminates, it has only been used in a limited number of applications. But that might be about to change thanks to pioneering research by engineers at ANU.

Fibre-metal laminates, or FMLs, are usually composed of sheets of light-weight metal, like aluminium, with a layer (or layers) of fibre composite in between.

"FMLs aren't new," says Mr Luke Mosse, a PhD student working on FMLs in the Department of Engineering. "They've been around for over a decade. They were originally developed as aerospace materials which were light and strong, and most importantly, exhibited excellent fatigue resistance. When cracks developed in the metal sheets they didn't have the capacity to grow because they were held together by the fibre composite in the core. This is important for planes and spacecraft where the propagation of a crack could lead to the rapid destruction of the vehicle."

Problems with thermosets

"They cost more to produce but that's okay for these high performance aerospace applications," he explains. "Unfortunately, there are several inherent problems with these original FMLs that mean that they aren't appropriate materials for more widespread industrial applications such as car panels.

"The main problem is that these first FMLs used thermoset polymers in the fibre composite layer sandwiched between the metal layers. Thermoset materials set on heating and then stay in that shape (even if reheated). This makes the creation of complex shapes difficult and expensive. The two metal sheets would need to be shaped and formed first. One would serve as a mould to which the composite would be attached. Then, before the polymer in the composite sets, the second metal skin would have to be added."

There's another issue connected to this. In addition to being time

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Developing FMLs

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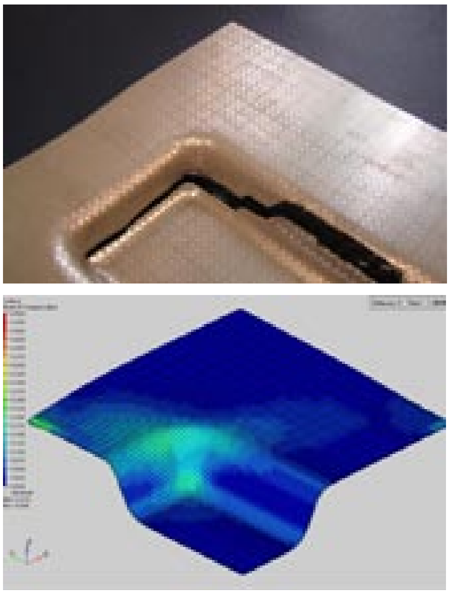
consuming and expensive to set up and produce, these thermoset-based FMLs cannot be recycled because the polymer cannot be reworked and reused. The expense and the lack of recyclability have meant that these traditional FML systems are not appropriate for most of the car market.

And yet there is a growing push in the car industry for the development of light weight materials that are as strong (or stronger) than the metals currently in use. Lighter, stronger materials would allow for the production of safer, more energy-efficient cars (with savings in greenhouse gas emissions). There are already some luxury cars that are using thermoset-based composites in their panels but so far no FML has been produced that is suitable for use in a mass production environment.

Stamping FMLs

In recent years researchers in the ANU Department of Engineering have developed a range of FML composites using thermoplastic polymers instead of the traditional thermosets as the core layer in between sheets of aluminium.

"Unlike thermoset polymers like expoxy, thermoplastic polymers can be reformed when they are heated," explains Mr Mosse. "This has several important implications. First, it means we can recycle them. Next, and very importantly, it means we can create flat sheets of this material and then, with the application of a bit of heat, we can stamp complicated shapes into these sheets.



Upper image: FMLs using the composite Curv failed through a process of the metal skin cracking. Lower image: Computer simulation is used to model the process. Lack of wrinkling behaviour and high strain in crack-initiation regions correlate with experimental results.

"Ultimately, what we're after is a metal/polymer composite that can be stamped into shape," says Mr Mosse. "It's not enough to come up with new light-weight, super-strong composite materials. They also need to be suitable for the mass production environment, and that means stamping."

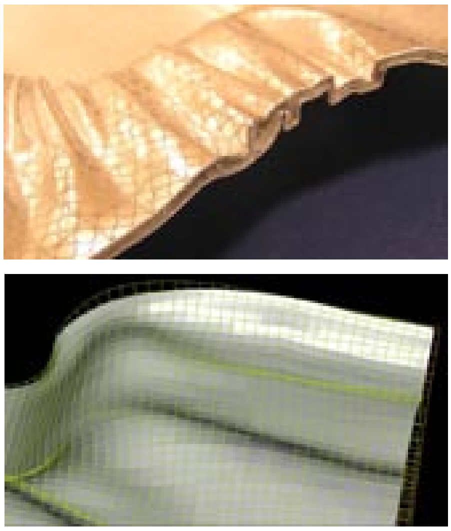
Stamping shapes out of sheet metal is a major part of many manufacturing processes, especially those in the automotive industry. It's big business with a high throughput. The Stamping Plant at Ford's Geelong manufacturing complex, for example, employs some 2800 workers. Each day it uses 320 tonnes of steel, handles more than 1200 different parts, and ships out 250,000 pieces! If FMLs could be developed to be processed in facilities like these it's easy to see how much more valuable this composite might be to industry.

Polypropylene FMLs

"My research is focussed on understanding how two different FML systems perform under a range of stamping conditions," says Mr Mosse. "Each FML uses a different type of commercially available thermoplastic polymers as the core layer. One uses a product called Curv. The other uses a brand called Twintex.

"Curv is made up of polypropylene fibres embedded in a matrix of polypropylene resin. By itself it's used in vacuum moulding to create products like parcel shelves in cars. Twintex is a fabric of glass fibres mixed with polypropylene fibres. By itself it's used to make some car components like bumper bars and it's also been used in snowboards.

"To create sheets of FML we



Upper image: FMLs based on Twintex failed by wrinkling (a completely different behaviour to the Curv-based FMLs). Lower image: The model for this system (the wire mesh = aluminium and grey = composite) also displayed this behaviour.

basically sandwich a sheet of Curv or Twintex between two thin sheets of aluminium. There's also a thin sheet of modified polypropylene adhesive placed between the composite core and the aluminium. The total layered sandwich is then placed in a heat press and fused together to form a light, high-strength plate that's only a couple of millimetres thick.

"Creating sheets of FML is relatively straightforward and could easily be scaled up for industry. Pressing that sheet into different shapes in a reliable and predictable fashion, however, is a more challenging proposition because little is known about how they will respond to stamping."

Modelling the system

"Understanding how FMLs perform when stamped is a lot more complicated than understanding a pure material like sheets of aluminium or steel," comments Mr Mosse. "Each layer in the FML has its own properties and the manner in which the system as a whole behaves depends on all of these plus what's happening in the critical interfacial zones between the layers."

To explore how the two FML systems perform, Mr Mosse has retooled the Department's stamping rig to carry out a series of investigations on what happens to the FML when stamped at different temperatures, pressures and speeds.

"Both the Curv and Twintex system will fail when stamped at conditions outside a certain temperature and pressure window," comments Mr Mosse. "However, it's interesting to note that the different systems fail in completely different ways. The FML with the Curv core fails by cracks forming across the aluminium along the lines where it's being stamped. The FML with the Twintex core doesn't crack but the entire composite sheet starts wrinkling around the stamping zone."

To understand what's happening Mr Mosse has modeled the various components making up the different systems and measured the forces at work during the stamping process. He's paid particular attention to the stresses acting on the interfaces of the various layers. In order to measure these interfacial shear forces between the laminate layers he needed to design and build a special lap-shear apparatus. This device allowed him to apply a controlled heat and pressure on the FML while simultaneously applying a measured force pulling the polymer core against its aluminium sheath.

"This type of work is a mix of empirical data collection, computer modeling and then testing and more data collection," says Mr Mosse. "The aim is to create an understanding of how the FML system is working so that you can predict with confidence how it will perform under a range of standard operational conditions experienced in the stamping process.

"We're still building the model at the moment but results so far suggest there's enormous potential for these FMLs to be used in mass manufactured stamping systems.

New horizons

"To the best of my knowledge we're the first lab in the world attempting to develop an understanding of FMLs for mass manufactured stamping systems. It would be great to see Australia lead the way in this area.

"While our focus has been on stamping FMLs for car panels there's likely to be a wide range of other applications for this work. For example, these composites have excellent energy absorption in impact and might serve in armour plating. When an object strikes the composite a lot of its energy is dissipated as the FML delaminates."

The work on FMLs is being sponsored by Ford Australia, and continues on a long line of collaborative projects between ANU and Ford in the area of stamping technology.

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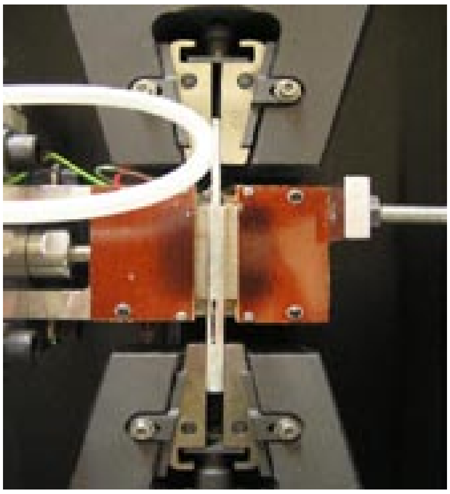

In order to measure the interfacial shear forces that exist between the laminate layers a special lap-shear apparatus was devised. Pictured above, this apparatus allowed the shear force between the middle composite layer and the metal layer to be measured simultaneously with temperature and external pressure (stamping pressure) on the FML.

The fabulous Faro arm

In researching the stamp forming of FML material systems the Faro arm facility in the Department of Engineering has been invaluable for generating both quantitative results and clear visual aids for journal publications and presentations. The Faro arm is a 'Coordinate Measuring Machine' that allows you to digitally trace a three dimensional surface to within less than a tenth of a millimetre. (Luke Mosse is pictured below using the facility.)

The first phase of Mr Mosse's study looked at the springback or shape error characteristics of FMLs compared to plain aluminium when stamp formed into channel sections. Previously, this task would have required the hand tracing of profiles of the channel sections, and then the determination of the degree of deviation between the stamped part and an ideal, perfectly formed part. This would have all been done by hand.

By digitally scanning the channels, cross-sectional profiles can be produced and compared to CAD (Computer Aided Design) geometry of the ideal form. A value quantifying the mean deviation of the stamped part from the ideal can be produced as well as yielding curvatures for any region of the channel.

The ability to overlay and compare cross-sections from a range of experiments has also produced new insights into the effects of the forming variables and material systems being investigated.

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Words of substance

"The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them."

Sir William Bragg (1862-1942)

Working with textiles

Where would you go to learn about discharge printing, lye crimping, carbonising cellulosic fibre and core-spun silk surrounded by viscose rayon? Sounds like a tour through a chemistry lab but you could learn about all these things and much more in the Textiles Workshop in the ANU School of Art. Which just goes to show how textiles and materials science have much in common.

Students attending the Workshop receive full instruction in the diverse range of traditional and contemporary textiles, from weaving, tapestry and surface design to feltmaking, dyeing and embroidery. The Workshop promotes a creative and innovative approach to textiles in a contemporary context incorporating a sound occupational health and safety environment and appropriate workshop practices.

"Our goal is to provide our students with a strong technical base across the textiles spectrum. This enables them to then develop and pursue their own specific interests," says Ms Annie Trevillian, Acting Head of the Workshop. "For some that will involved the creation of woven fabrics using a variety of fibres. For others it may be more about printing, dyeing or chemically treating existing fabrics. Working with textiles involves a good understanding of their physical properties and a knowledge of textiles chemistry enables students to be innovative.

"And students aren't restricted to just working with textiles. They are schooled in drawing by Noel Ford and computer-aided design by Sharon Boggon. Our students are encouraged to explore the whole range of artistic expression.

"Having said that, anyone can produce images of anything these days with the right technology. However, I believe there's a special satisfaction in creating a visual message in the medium of textiles. It takes more time, and involves research, experimentation and persistence, but the final product is worth it."

The staff in the Textiles Workshop bring with them a formidable array of skills and backgrounds. Valerie Kirk, Head of Workshop, currently on leave to produce the Nobel Tapestries (see box), is an internationally acclaimed tapestry artist. Annie Trevillian and Jill Pettifer are experts in the safe chemical treatments of fabrics for Australian conditions and have published a resource manual called *Bleach Buckle and Burn* for Australian practitioners. Jennifer Robertson is an internationally renowned textile artist and is currently the recipient of the ArtsACT Creative Visual Arts Fellowship working on a new body of woven textiles for furnishings. She also collaborates with the Nuno Corporation in Tokyo. Monique van Nieuwland is the Workshop's Technical Officer, and brings with her expertise in weaving, print, and mixed media.

In addition to being grounded in the technical aspects of working with a diverse range of textile materials, students develop a historical perspective and conceptual, creative and critical abilities.

Facilities available in the Textiles Workshop include tapestry looms for large and small scale work, floor and table looms for weaving, a computer-linked dobby loom for computer-aided weaving, dye house and steamer, modern hank and cone winding machinery, fabric printing facility, knitting and sewing machines and rug-tufting equipment. In addition, the Workshop has areas for display and general drawing and design. Facilities for computer-aided design are available in the Workshop with specialist textiles software and graphic packages.

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More info: http://www.anu.edu.au/ITA/CSA/textiles/index.html

Anne Peters weaving double cloth structures on a table loom. Other looms in the weave studio include computer-aided looms and Swedish floor looms.

Annie Trevillian surrounded by lengths of 3-colour fabrics designed and screen printed by second year students as part of their introduction to surface design.

Detail of a tapestry in progress by Noriko Nakano, a Masters student from Japan.



The Nobel tapestries

University House will soon have three stunning new works of art adorning its walls. Each will celebrate the research associated with a Nobel Prize connected with the ANU, however these works will be rendered not in paint but in wool.

Ms Valerie Kirk has been commissioned by the ANU to create three tapestries to celebrate the 50th birthday of University House. They will reflect on the Nobel work of Sir John Eccles (ionic mechanisms of the nerve cell), Lord Howard Florey (penicillium and antibiotics) and the team of Professor Peter Doherty and Professor Rolf Zinkernagel (cell mediated immune response).

"A painter creates different tones and hues by mixing their paints together and applying these with a brush onto a canvas," says Ms Kirk, Head of the Textiles Workshop at the ANU School of Art. "Tapestry weavers create their own palette of colours by winding different coloured strands of wool onto a bobbin which are then threaded through a network of tightly stretched strings called a warp. When you consider that around 12 strands of different colour are wound onto each bobbin you begin to see the range of possibilities.

"And wool is such a wonderful material with which to work. It's vibrant, light absorbing, provides a good density of colour, and has a solid feel. When used as the building blocks of a large tapestry it can have a powerful impact."

To create the images that will form the tapestries, Ms Kirk has studied a range of material associated with the three Nobel Prizes and visited the John Curtin School of Medical Research. She even asked for a scanning electron micrograph of the penicillium mould that was the focus of Florey's Nobel Prize.

"This has been a fabulous experience for me," she says. "In order to create the images for the tapestries I have been allowed to immerse myself in the science history of the university, something which is completely new to me.

"In the designs of the tapestries I've attempted to evoke a sense of the original research by using elements of the somewhat simple two dimensional diagrams used to describe their work. However, I'm combining these with images of a more contemporary digital nature that now surround these areas of science. Also, if you look closely, you'll see a few tell-tale details of the research trade; an arrow here or a scale bar there."

Valerie Kirk at work on the beginning of a tapestry reflecting the Nobel winning research of Peter Doherty and Rolf Zinkernagel. A black and white 'plan' of the tapestry sits behind a network of strings (the warp) through which the wool is woven. Spools of yarn of different colours serve the artist's palette.

Ms Kirk has finished the tapestry on the research of John Eccles and is just beginning the one on Doherty and Zinkernagel. Each tapestry measures 1.2 m wide by 2.4 m deep and take around four months of full-time work to complete.

"Tapestries by their very nature are enormously time consuming to produce," says Ms Kirk. "They are done all by hand, and you're making decisions all the time on the mix and blend of various colour tones and combinations, constantly reviewing how the balance is developing. However, the final result makes the effort worthwhile, a vibrant, eye-catching work of art that will last for a long time to come."

Nanoindentation on the south coast

In late March, around 60 people travelled down to the farm-like setting of the University's Kioloa Coastal Campus for two days of focussed discussion on nanoindentation. It's not a topic most people are familiar with and yet this workshop could well prove to be the start of something with enormous potential.

"The meeting was noteworthy for a wide range of reasons," says Dr Jodie Bradby, convenor of the Australian Nanoindentation Workshop. "To begin with, this was the first meeting of its kind in Australia on nanoindentation, bringing together experts on the topic from all over the world."

As the name suggests, nanoindentation is all about indenting a range of materials at a nanoscale, a process that is usually carried out with a diamond-tipped probe. It's about understanding the nanomechanical properties of different materials as well as the opto-electronic changes that can be induced in a material by applying localised force at the nanoscale.

"Nanoindentation is an essential tool for nanotechnology," says Dr Bradby. "It's important that Australia builds some capacity in this area to ensure we can capitalise on emerging opportunities.

"This is especially appropriate when you consider that Australian researchers have led the world in many areas of nanoindentation. Professor Mike Swain, for example, developed the UMIS 2000, one of the world's first nanoindentation machines while at CSIRO. (Mike is now based at the Uni of Otago and was one of the presenters at the workshop.)

"However, despite the fact that we have local expertise in nanoindentation, up till now there has been no strong network of researchers involved in the field," comments Dr Bradby. "More than anything else, that was what we were hoping to achieve with this workshop – to begin building a network of contacts and expertise in nanoindentation.

"And I think we've made an excellent start. We were hoping we might get 30 people involved but as it turned out it was more like 60 people made the effort to get there. Half were PhD students, ten were postdocs with the remainder being career researchers.

Nanoindentors unite - students and researchers gather to talk up nanoindentation.

"The participants represented a wide range of institutions including 9 different universities across Australia, ANSTO, and several different divisions of CSIRO. In addition we had participants from NZ and the USA."

"The presentations and discussions were enthusiastic and lively, and I think we've gone a long way towards building an enduring network."

"Which leads me on to the other important aspect of this workshop. This was the first science networking event making use of support from two of the new ARC research networks: the Australian Research Network on Advanced Materials and the Nanotechnology Network.

"Each network provided $5000 in sponsorship which allowed us to offer free registration for students and a discounted rate of $100 to early career researchers. The sponsorship also allowed us to offer travel subsidies for students to offset the cost of flights or car hire. Five such awards were made totalling around $1500.

"Involving the students and early career researchers in events like this is critical to building vital and evolving networks. I think the support shown by these two ARC research networks has gone a long way towards making it the success that it was."

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PS: ANU is about to receive a new state-of-the-art nanoindentation machine in June. Materials Monthly *will present a more detailed story on the new device and background on nanoindentation when it's up and running.*

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