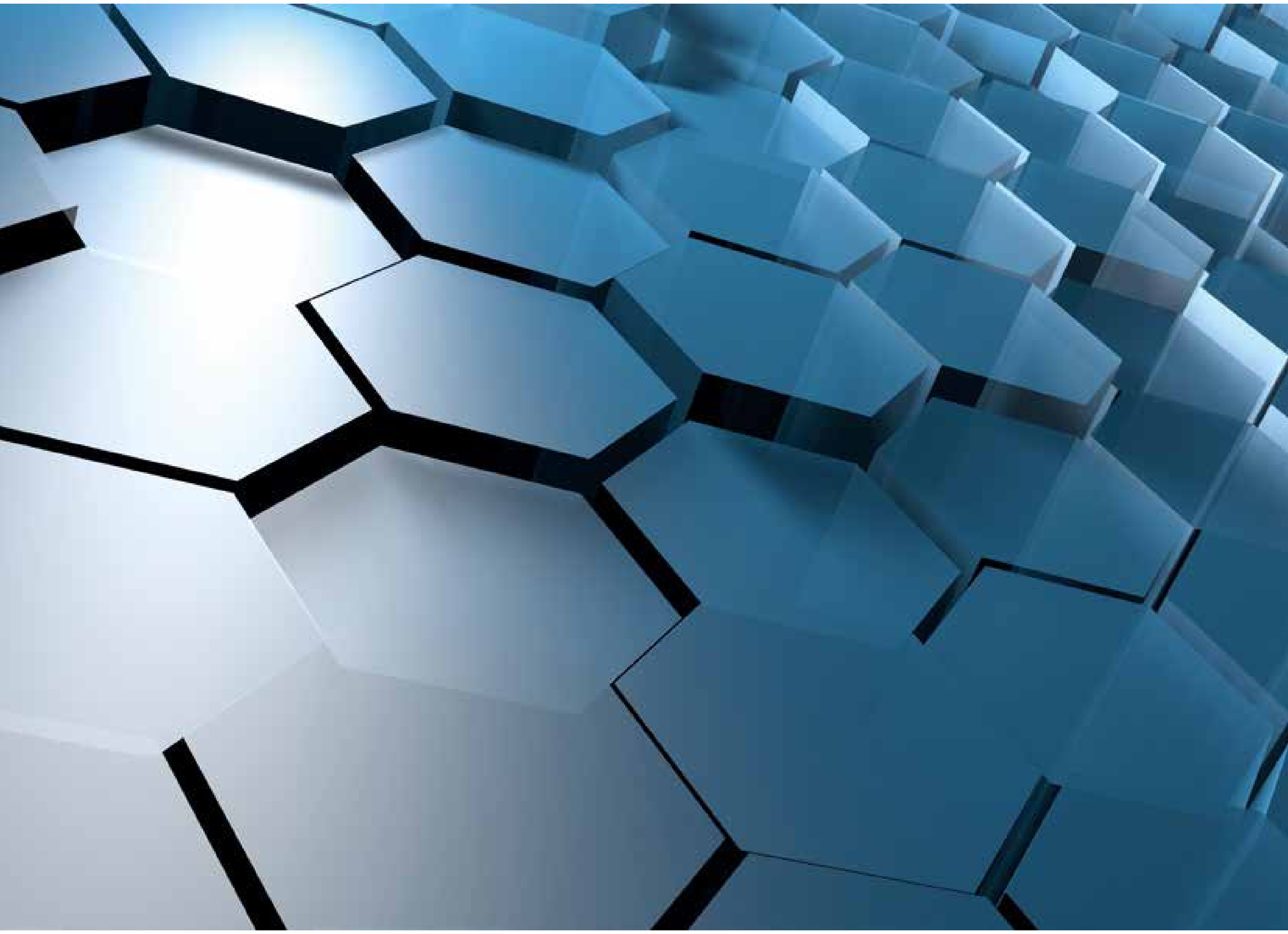
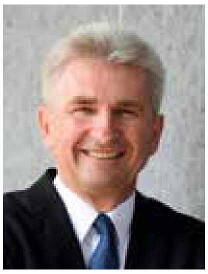
ProduktionNRW
Cluster Maschinenbau/Produktionstechnik



Innovations made in NRW
Lightweight drive meets heavyweight technology

Content

Innovation potential has a leveraging effect



Prof. Dr Andreas Pinkwart
Minister of Economic Affairs, Innovation, Digitalisation and Energy of North Rhine-Westphalia

Dear readers,

North Rhine-Westphalia is one of the world's leading industrial locations. Our federal state is not only home to many 'hidden champions' and companies with a global ambit, but is also a top-level, state-of-the-art location for high-tech and R&D. It has the highest density of universities anywhere in Europe.

Sciences and the economy are traditionally closely networked here. North Rhine-Westphalia thus has the best conditions in place for our goal of becoming Germany's top location for innovations in mechanical engineering and plant construction.

The development of new materials, for lightweight design in particular, is a key factor in ensuring the competitiveness of our mechanical engineering and plant construction industry, and offers genuine added value. Lightweight design makes products better, and saves resources and costs. It offers huge potential for innovation, and has a leverage effect that radiates into other sectors.

North Rhine-Westphalia is already well positioned when it comes to lightweight design. If we want to expand our competitiveness still further, our businesses must think and act beyond sector and material boundaries. The power of innovation in lightweight design can bolster NRW as a location, as long as our businesses seize the opportunities that are offered. It is up to the state's policy-makers to create the necessary room for individual initiative and innovations. This something that we are working on, every day.

In its magazine "Innovations made in NRW", the state cluster ProduktionNRW illustrates some highly promising approaches to all aspects of lightweight design, highlighting in the process the innovative skills and power of performance offered by lightweight design, and offering important stimuli for new applications and concepts that cross sector boundaries.

Yours,
Prof. Dr Andreas Pinkwart

Networking: The dynamic ‘critical mass’

Wolf D. Meier-Scheuven
Cluster Spokesman
ProduktionNRW

Dear readers,

Clusters bring players together: they provide a network for the economy, sciences and policy-makers, and serve as a communication platform for an exchange of knowledge and information. That’s also the case for the ProduktionNRW Cluster, whose magazine “Innovations made in NRW” regularly deals with subjects that move the industry in NRW.

This second issue focuses on lightweight design. It’s a topic you can’t avoid when it comes to seeking a solution for the challenges of the future. Of course, lightweight design has been a part of industry for some time, but what’s new is that it is gaining a new dynamism as technologies become more refined. A lot has become possible now that would have been inconceivable or not feasible just a short time ago.

Strong pressure to innovate makes mechanical engineering a research-intensive industry. Small and medium-sized enterprises in particular, which form the backbone of the industry in North Rhine-Westphalia, would find it impossible to manage the complexity of a broadly networked R&D structure entirely on their own. Networking in the form of collaboration with partner companies, research institutes and universities is therefore an important extension of their own capacities.

With its focus on lightweight design, this issue of “Innovations made in NRW” takes the theme and illustrates a series of success stories and projects that have been implemented by institutes and partner entities in the industry. ProduktionNRW shows how companies and collaborative entities can develop new products and processes for the industry and create innovative solutions.

We hope these new ideas and approaches will prove a source of inspiration as well as new technological possibilities!

Yours,
Wolf D. Meier-Scheuven

Lightweight design – a technological heavyweight

WALTER BEGEMANN

Lightweight design takes many forms and has many different applications. A practical approach for the long term is to use different materials in combination, which involves working together across sector boundaries. Industry and research in North Rhine-Westphalia are well set up to deal with this challenge.

Photo: BMW

Hybrid construction methods are used for vehicle bodywork. Electric mobility is a driver of lightweight design. Steel is increasingly combined with other materials such as fibre-reinforced polymers.

Lightweight design is nothing new. Nomadic peoples relied on light, movable dwellings, and the glider used in Otto Lilienthal's first controlled flight weighed just 20 kilograms. Today, aircraft manufacture and the automobile industry have assumed an important function as drivers of lightweight design solutions. The chief benefits are fuel savings and a reduction in climate-harming emissions – and political requirements in these directions are growing more stringent around the world. Applications are also to be found in the transport industry, shipbuilding, the wind industry, the construction sector, and in mechanical engineering and plant construction.

What does lightweight design mean?

Weight reductions and their obvious benefits are only one aspect of lightweight design. It involves performing a function with minimal use of materials. And despite a reduction in weight, the overall system must continue to meet requirements in terms of stiffness, strength and dynamic stability throughout its service life. The quality of a lightweight design therefore necessitates coordination between design principles, materials and production. Economic, environmental and social requirements also impact on lightweight design solutions. The objective is to save raw materials, energy and costs during production and use of the product, all the way through to the recycling stage.

Trends and challenges

Aluminium was used alongside steel in mass-produced car bodies as early as the 1990s. Production of the first passenger cell for the BMW i3 using carbon fibre illustrated the potential offered by composites for lightweight design in automobile manufacture. In the future, however, lightweight design solutions will be increasingly based on a combination of composites with aluminium, steel and other materials, known as hybrid lightweight design. Long-term success will be found in an intelligent mix of materials with a high level of functionality that will meet the product and cost requirements of the specific application.

Accordingly, design engineers and developers will need more know-how about materials, processing methods and joining and combination methods in future. On the way toward series production, savings potentials lie mainly in process costs, besides the materials themselves. Currently, system development is moving toward complete production facilities for series applications. This will require cooperation at an early stage with user industries and research institutes. The core tasks include handling of different materials, customised manufacture and achieving digitalised process chains (Industrie 4.0).

Mechanical engineering as a driver of technology

The mechanical engineering and plant construction industry offers solutions that are right for increasingly mature production processes and automation in lightweight design. German Engineering Federation VDMA brings together professional associations and working groups along the value chain in its Hybrid Lightweight Technologies working group. The VDMA State Association in NRW ensures there is an intensive regional connection with members.

In addition to VDMA members, the opportunity to participate in the working group (with its more than 200 members) is open to users, suppliers and research institutes. The goal is to refine production processes, automation and joining technologies across material boundaries and throughout Europe, and to create viable jobs for the future.

Members engage in discussions on technological developments in smaller working groups. One recent result was the publication of the VDMA guideline on technologies in hybrid lightweight design. This comprises 25 technology profiles on manufacturing and joining processes. The working group helps its members to collaborate with each other and with interested customer sectors via conferences and by acting as honorary sponsor for the Composites Europe trade fair. Cooperation also includes exchanges with three partner organisations as part of the Composites Germany trade association.

With political support

Lightweight design as a key technology gets particular mention in the Federal Government's coalition agreement. Rigorous efforts must be made to pursue and further the promotion of this technology to broaden the range of industrial applications. Even during the previous parliamentary term, the Federal Ministry for Economic Affairs and Energy set up a lightweight design initiative and an office to encourage dialogue on industry policy. The VDMA Hybrid Lightweight Technologies working group is represented in the advisory board of the initiative, and works with it on developing a lightweight design strategy.

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Photos: Dlugosch

With the increasing importance of mobility comes a need to make sparing use of resources. A mix of materials is used for lightweight wheel rims.

Automated weaving of carbon fibres makes lightweight structures possible.

A new pathway to fibre/metal laminates

ALAN A. CAMBERG AND TOMAS HEGGEMANN

The latest car body concepts increasingly rely on an intelligent multi-material mix. True to the motto "the right material in the right place", this idea is consistently pursued and devolved to the thickness of materials. The result: a multilayer composite of metal and fibre-reinforced plastics that is fit-for-purpose.

Photo: Thyssenkrupp Steel Europe

InCar-Plus demonstrator.

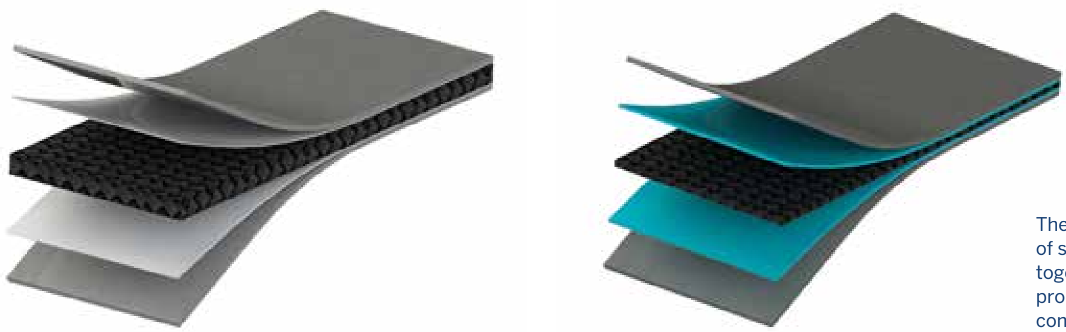
The ambitious goal of this project demands all-round expertise, which is provided by an interdisciplinary consortium of six professional groups from the Institute for Lightweight Design with Hybrid Systems at the University of Paderborn and ten industry partners: D&S Sandstrahltechnik, Benteler Automobiltechnik, Siemen GmbH & Co. KG, Thyssenkrupp Steel AG, Spier GmbH & Co. Fahrzeugwerk KG, Erichsen GmbH & Co. KG, ESM GmbH & Co. KG, WIB GmbH, Maschinen- und Anlagenbau Meyer GmbH & Co. KG, and SI-Coatings GmbH.

Despite their outstanding lightweight construction properties, fibre-reinforced plastics have disadvantages for car body design, such as unfavourable failure behaviour and high production costs. In the case of hybrid metal with fibre-reinforced polymer composites, attempts are made to combine the individual materials in such a way that their disadvantages are eliminated, and optimum mechanical properties are achieved at economically acceptable costs. However, depending on the use, the geometry of the cross-section and the chosen layer structure, the weight-specific properties of these materials may vary widely.

The project approach

To counter these limitations, an innovative approach is being developed which enables a methodical technique for the development of layered materials to match requirements. The LHybS project – lightweight construction through innovative hybrid materials – sets itself the ambitious and innovative goal of promoting materials development on the basis of a top-down approach. It is supported by the

Graphics: LUF Paderborn



The new hybrid materials consist of several layers that are bonded together. Their interaction allows production of an optimised component.

EU's European Regional Development Fund and the State of North Rhine-Westphalia under the direction of the lead partner, the Jülich project management organisation.

The thickness-dependent property profile of the material to be developed is derived from full vehicle simulations and takes into account the purely mechanical aspects as well as all requirements resulting from the use of the material for a selected component. The aim of the project is to manufacture a lightweight, hybrid semi-finished product that can be handled in a similar way to the materials currently used in car body construction. This challenging task requires multifaceted know-how created within the project by an interdisciplinary consortium of six researchers from the Institute for Lightweight Construction with Hybrid Systems (ILH) together with ten industrial partners.

From full vehicle simulation to material

The starting point for material development is the InCar-Plus model from Thyssenkrupp Steel Europe. The bodywork of the InCar-Plus represents a steel-intensive lightweight construction approach and relies primarily on high-strength and ultra-high-strength steels and, consequently, is suited to state-of-the-art technology. For evaluation purposes, the reference structure is subjected to a series of crash and NVH (Noise, Vibration, Harshness) simulations. These are to evaluate the actual state and the subsequent study of components with a high hybridisation potential.

As a concept for identifying car body components, a method is being developed to investigate the influence of individual components on the overall properties of the bodywork. For this purpose, components with proportionately high deformation energy are pulled out and subjected to a sensitivity analysis. This will guarantee that material development is carried out on components where the extra costs are justified by significantly improved body properties. The identified demonstrators – the front longitudinal member section as an example of a crash-relevant component and the rear cross member as a stiffness-driven component – form the basis of optimisation-based material development.

Then, both demonstrators are divided into at least five individual layers, of which the material properties are freely parameterised in the first stage of optimisation. As soon as the algorithm finds an optimum, the idealised material properties are compared with a real materials database to identify actual material matches.

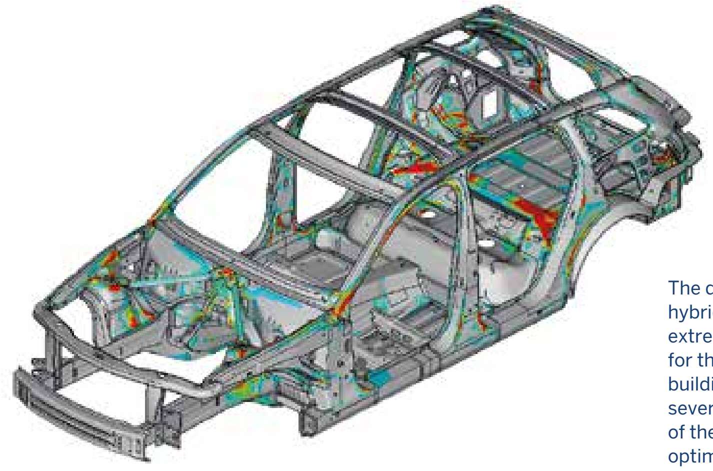
Finally, the developed layer composites are validated in full vehicle and bodywork simulations and compared with the values of the reference structure. In both cases, a mass reduction of at least 20 percent with the same or improved body properties can be achieved just by developing new materials.

Deep-drawing of Fibre/ Metal Laminate (FML) materials

Forming technology plays an essential role in the production of flat body parts. In the LHybS research project, two body components are to be produced from FML blanks by deep-drawing. Complex pull and pull-push stresses occur in the components during the forming process.

The use of an unfavourable tool or process design may lead to failures, such as ruptures or wrinkles, even when forming conventional metal sheets. Other potential errors may occur in the process of forming FML sheets. For instance, in places where tangential

Graphic: LUF Paderborn



The development of innovative hybrid materials is aimed at extremely lightweight components for the automotive industry. In the building stage, which consists of several materials, the interaction of the materials results in an optimum component.

compressive stresses prevail, the fibres may be moved or compressed. This may have undesirable consequences, such as delamination and buckling or breaking of the fibre strands. Apart from such damage to the fibre, delamination can lead to a loss of cohesion in the matrix, which means that the component can no longer be used in a practical way. Another problem may occur in places with a high surface pressure. In that case, the matrix material may flow out of the material compound. However, these undesirable effects can be successfully counteracted.

Material design suitable for forming

In the project, complementary numerical and experimental methods were developed and used to develop a tool and process design adapted for FML forming. In the forming simulations, data from the InCar-Plus model were the basis for modelling tool elements in the forming process. The simulations were initially used for fundamental analysis. For instance, that is how the effect and interaction of variations of individual design and process parameters on the forming process were determined. Experimental work with increased complexity was also carried out. In this work, typical stress situations during the forming of real components were evaluated by making replacement geometries (bowl, hemisphere geometry and U-profile). This provided important findings to develop guidelines for process design and semi-finished product design for deep-drawing FML components. The improved forming behaviour of the adapted FML sheets can be enhanced by using adjustable multi-point down-holding and stamping systems, so that even complex components can be produced.

Fit-for-purpose material profiles

With the help of the optimisation methodology created within the framework of the project, fit-for-purpose material profiles can be designed that enable the development of further lightweight construction potentials. To increase the bonding strength of FML, suitable methods for surface structuring, as well as bionic-based adhesion promoter systems, are being investigated. To enable processing of innovative materials into components in deep-drawing processes, adjustments to the material itself as well as to the forming tools and the process management are being looked at in detail.

To date, the developed material composites have been characterised by numerical simulations and substitute tests only. The experimental validation of FML materials on real component geometries is still pending and is currently in the preparatory phase.

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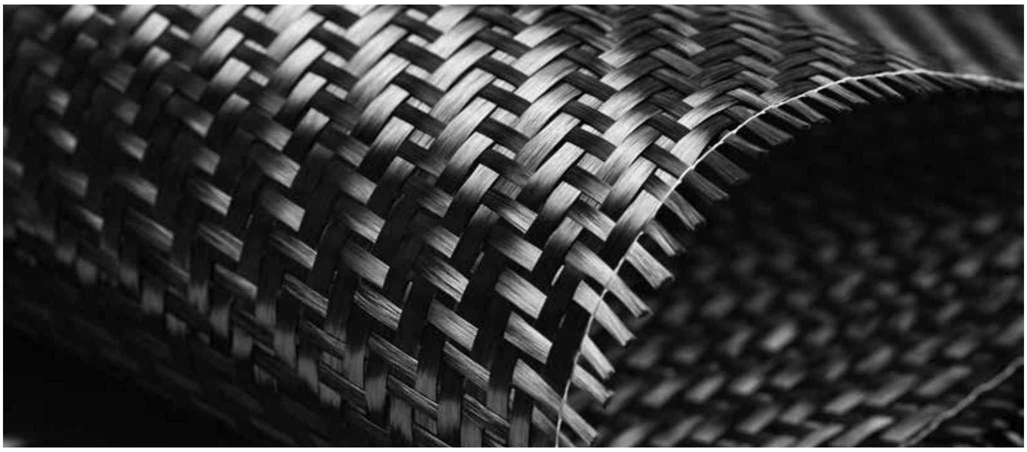
Taking global challenges as opportunities

Lead market agency LeitmarktAgentur.NRW offers financial support to research institutes and companies for innovative projects via its lead market competitions. This is a way for NRW to promote the development of new products and processes and bolster the state as a business location.

Photo: vitals/ Adobe Stock



New materials can be used in a variety of materials. The mixture of materials allows components with optimum properties in many applications.

Constant population growth, increasing urbanisation, climate and environmental protection, changes in mobility, and a clean yet reliable energy supply system – these are some of the major challenges facing the world. This leads to opportunities for those companies that offer innovative solutions in these key and future-oriented industries.

The state government would like to see as many as possible of these companies coming from North Rhine-Westphalia. They need to launch new products and processes onto the world market and ensure their long-term competitiveness in the process. This helps to secure NRW as a business location – and secure many jobs in the state, too. This is why NRW has developed a lead market strategy to provide financial support for research projects, the results of which businesses will drive forward to series production level in a later stage.

Eight lead market competitions form the heart of the lead market strategy: mechanical engineering and plant construction, new materials, mobility and logistics, the IT and communications industry, the energy and environmental industry, media and the creative industries, healthcare, and life science. Projects may be submitted for sponsorship in any of these areas. The projects from the lead market competitions are financed with funds from the European Regional Development Fund (ERDF). For the current grant period (2014-2020), Brussels is making EUR 40 million available for each lead market. The state is contributing a further EUR 20 million in each case. The total budget for the current financing phase is thus not far off half a billion euros.

Focus on cooperative projects

"Since 2014, we have issued well over 1,000 individual approvals," says Dr Sebastian Dziallach of LeitmarktAgentur.NRW, which has been engaged to organise the competitions. This is a collaborative arrangement between the two project sponsors, PtJ (Projektträger Jülich) and ETN (Energy, Technology, Sustainability), and is domiciled at the Jülich Research Centre, like the two parent entities.

By far the most approvals were issued for cooperative projects, in which companies, universities and research facilities take on a particular topic together. Each partner in these cooperative groups receives a separate approval for its component. Projects from individual companies are a rare exception. It is unusual for the jury of experts to trust an individual company to be on the path to a ground-breaking innovation. "There must be an express emphasis on cooperative thinking and technology transfer," says Dziallach.

Contact for LeitmarktAgentur.NRW

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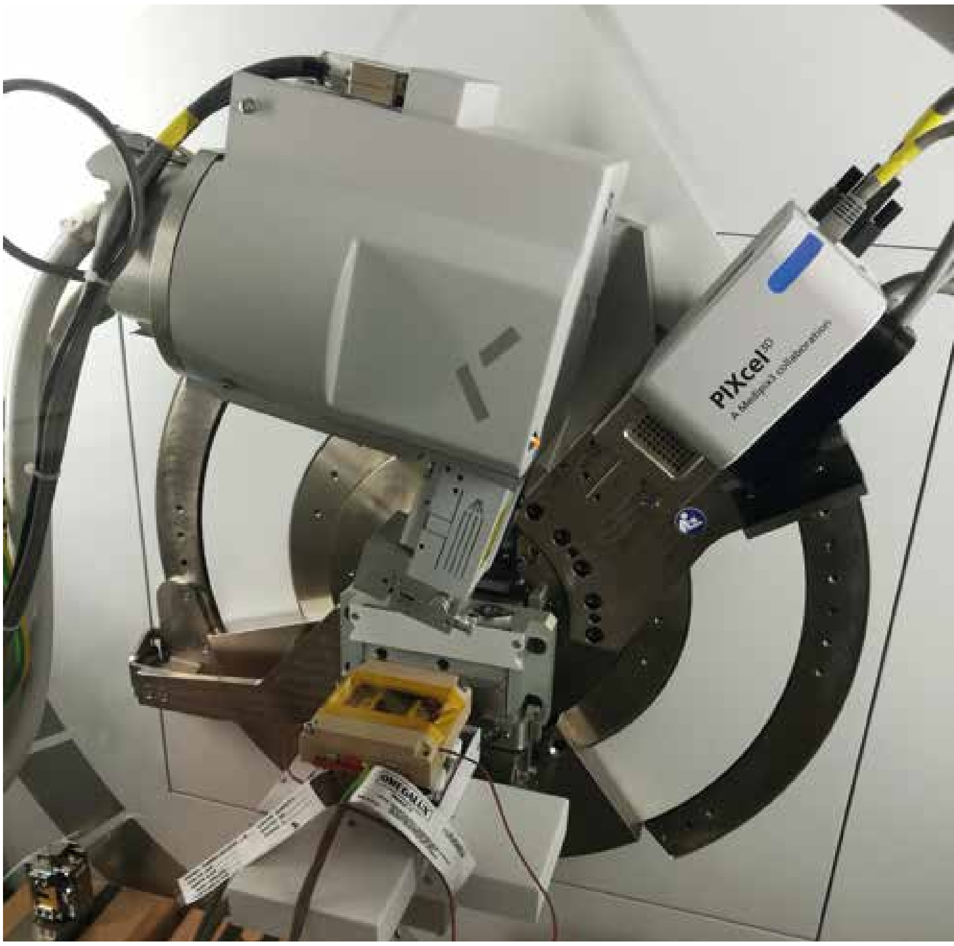
Lead market competition

It’s all about the material mix

Photos: Arne Busch



This equipment can be used to test the internal stress at different sample temperatures.

It’s no longer a question of new materials “versus” established materials. The goal now is to use the best material for the right purpose. This is precisely the objective of the InHyb project of the University of Siegen, carried out in collaboration with an industry partner.

The project is focused on combining glass fibre reinforced polymer (GFRP) components with steel. For example, the researchers at the university’s Department for Material Systems for Automotive Lightweight Construction are investigating the leaf springs connecting a wheel axle with the chassis – i. e. non-rigid components, which have to change in shape on application of a force. Most such leaf springs are currently made of steel, although springs made of GFRP are used in some luxury automobiles and commercial vehicles. Such springs are much lighter than conventional springs, but also much more expensive. When glass fibre is combined with the steel, the product is heavier, but also more robust – the idea behind the project is therefore essentially to get the best out of both materials. The extent of the weight saving from the use of this hybrid composite will be known only at the end of the project, but there is certainly considerable potential. A GFRP leaf spring is 70 percent lighter than its steel counterpart, for example.

For their “Intrinsic hybrid composite for cyclically stressed components” project, the researchers have joined forces with an industry partner, Mubea Fahrwerksfedern from Attendorn in the Sauerland area, an automotive component supplier that has been actively engaged in lightweight construction for many years. Their project has been submitted as a joint entry in the NeueWerkstoffe.NRW competition organised by the lead market agency for the German state of North Rhine-Westphalia (LeitmarktAgentur.NRW). For their three-year project, due to be completed at the end of January 2019, the project partners have received more than 70 percent of their total budgeted expenses of almost one million euro as a project grant from the agency. The remainder of the costs will be split between the partners.

Supplemented production process

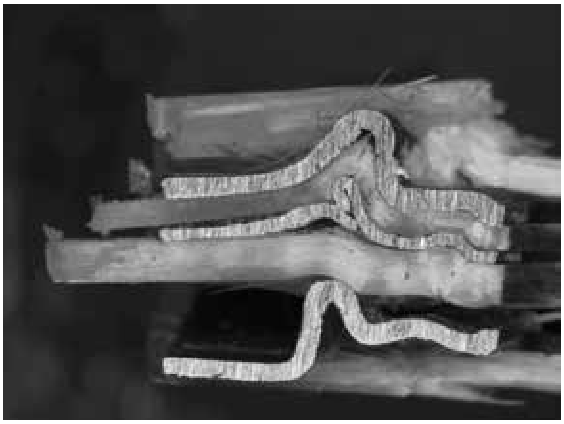
For the manufacture of GFRP leaf springs, glass fibres are pre-impregnated with epoxy artificial resin, placed in moulds and heated in a press. This liquefies the resin, which bonds with the fibres. During the pressing operation, the material hardens, resulting in a finished component. “That basic process provides the foundation for the technique employed in InHyb. We are combining several materials. Glass fibre plus polymer is already a multi-material system, but we also add steel to the mix”, says Arne Busch, who is running the project under the supervision of Prof. Dr Robert Brandt. Rather than changing the conventional production process, InHyb is merely extending it, he says, in that now a steel element is also laid in the press, and pressed together with the pre-material. On hardening, this results in a hybrid composite of FGRP and steel. Glass fibres are mainly unidirectional, i. e. laid only in one direction, and therefore are particularly strong only in one direction – so the use of steel achieves strength in all directions.

A problem still remains, in that steel and FGRP expand by different degrees on the application of heat, and contract to different extents on cooling. This creates internal stress within the hybrid composite. “There’s no getting away from it – that stress is always going to be there, but we are working on reducing it to the minimum possible, by finding the optimum composite structure”, says Busch.

Improved jointing technique

This material mix offers benefits not only for entire components, but also for the bonding of different materials. Take the example of joining a flat GFRP component to a flat steel component with a bolt connection. The ends of the two components overlap, so a hole is drilled in them, and a rivet is inserted. “If we now apply tractive force to the two ends, i. e. pull on the two ends, the GFRP would fail in short order, because there are no fibres running transverse to the direction of application of the force. The only resistance would be from the polymer matrix, which is however very weak, and would soon be destroyed in this situation”, says Arne Busch. Polymers have a strength of only 70 Megapascal (MPa) on the application of force. In comparison, GFRP materials in the direction of the fibres reach strengths of 1,000 MPa. InHyb aims to provide a more robust connection by introducing steel as the reinforcing material. “If we lay two metal sheets over and under the GFRP component in the region of the hole, and now pull on the ends again, the matrix will have a significantly longer time to failure”, explains Busch.

The basic research stage of InHyb has been completed. The project partners are now working on testing samples closely replicating the structural components. The next step will be to build a “demonstrator”, to show whether the product will actually work as they hope it will. “But even then there will still be a lot to do. It won’t just be a matter of completing the project with a finished component and putting it straight into serial production”, Busch says. “This project has been a development exercise, to see just what is possible in this area”.



The situation that InHyb is trying to prevent: the bolt has deformed the metal sheet and damaged the GFRP material.

Lead market competition

A crash box made of wood

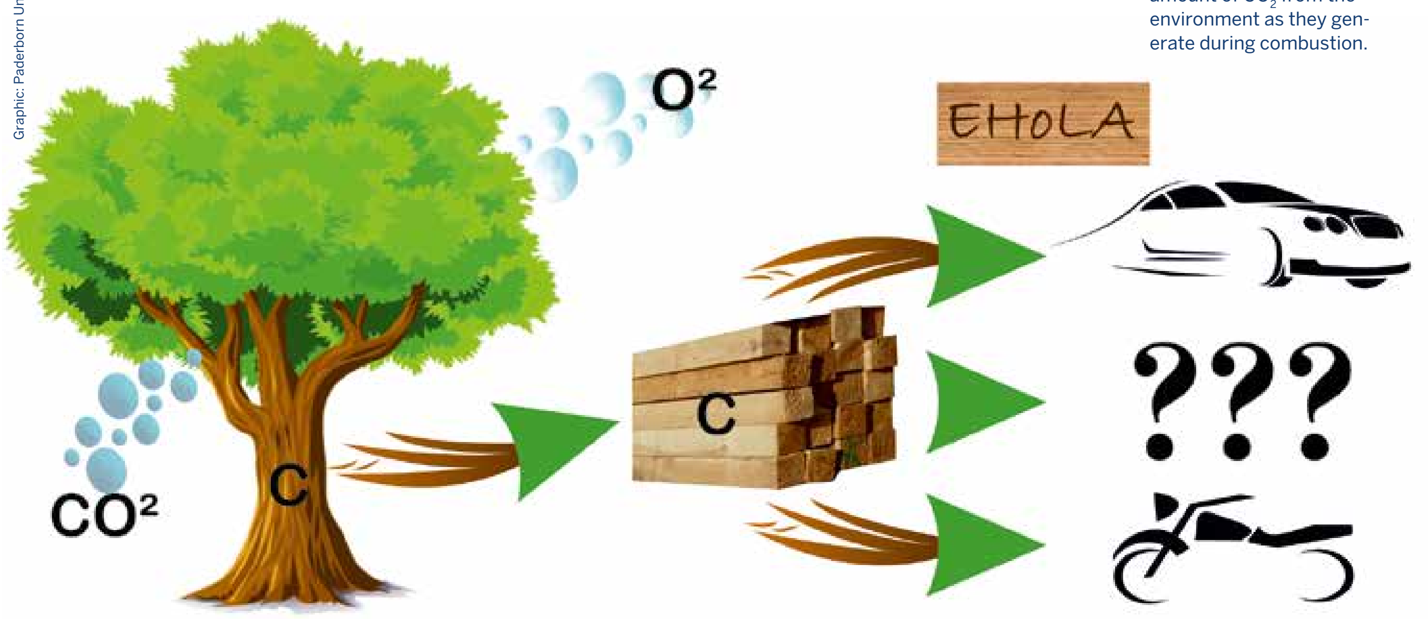
The automotive industry is facing the challenge of drastically reducing CO_2 emissions. One of the options for achieving this is lightweight construction, because lighter vehicles use less fuel. The EHoLA project led by the University of Paderborn is exploring the use of wood as a substitute for the customary heavier metal materials.

Reducing vehicle weight with the use of alternative non-steel materials is nothing new in the automotive industry. Examples include aluminium, and more recently carbon fibre reinforced polymers (CFRP). These materials may be lighter, but they also have their disadvantages. Aluminium production is an energy-intensive process, which also generates high CO_2 emissions. The production of CFRPs is also highly energy-intensive, and therefore relatively expensive. The material is also very difficult to recycle, since all the constituent substances have to be carefully separated. Accordingly, automakers are now exploring the option of using wood as an alternative material, previously only to be found as part of the interior trim in luxury limousines.

Good mechanical properties

With the aim of proving that wood is more than just a decorative material, and suitable for other vehicle components, even under the bonnet, a project has been set up in the Automotive Light Construction (LiA) department at the University of Paderborn, together with partners from industry. The researchers have shown that wood has similar properties to CFRPs or even steel, and in principle is therefore suitable for use as a vehicle construction material, provided it is appropriately optimised for automotive applications. In 2016, the research partners submitted their EHoLA project (from the German for "wood composites with optimised properties for environmental lightweight construction for automobiles") as a joint entry in the Neue-Werkstoffe.NRW competition organised

Graphic: Paderborn University



Wood as a material stores carbon for the long term. It is also climate-neutral, since trees draw the same amount of CO_2 from the environment as they generate during combustion.

by the lead market agency for the German state of North Rhine-Westphalia (LeitmarktAgentur.NRW). In fact, the competition judges were so impressed with the project that the agency has agreed to provide funding to the tune of around half a million euro to keep the project running until the start of next year.

Photo: Paderborn University

Cutting the wood veneers is carried out as a manual process.

The first phase of the project was to test the suitability of wood materials in general. The team found that veneer wood materials in particular are well suited for the purpose. Unlike solid wood and single-layer materials such as particle board, veneer wood materials comprise multiple layers. This allows the superimposition of materials with different properties, in terms of stiffness and strength, for example. This provides many different options for creating a wood material with exactly the required functional characteristics.

High energy absorption

In the next stage of the project, the partners focused on two specific structural components that could be designed and made of wood, rather than steel or aluminium as previously: the body components of a crash box and a seat back panel. Tests carried out on the crash boxes made of single-layer wood structures showed that wood absorbs energy at least as well as aluminium profile sections. And that was just the beginning – because these tests were carried out with aluminium sections specifically developed for high energy absorption. But the wood material used – beech, in this case – still left plenty of potential for optimisation. The selection of the base wood species for a wood composite depends on the required characteristics in each case. Beech provides greater strength and stiffness, but conifer woods are generally lighter. So another option can be sandwich structures, in which a soft wood material has harder timber layers on either side.

Wood is much lighter than steel, and even than CFRPs. Steel has a density of 7.8 grams (g) per cubic metre (m^3), as compared with just 1.6 g/m^3 for CFRPs. Yet wood comes in at only half that density, at 0.8 g/m^3. In addition, wood is a renewable material, and therefore not a diminishing resource. And at the end of its life cycle, it can be used as a source of energy – in other words, burned as fuel.

Precise division of roles

The EHoLA project is a collaboration between the LiA department at the University of Paderborn and two industry partners from the state of North Rhine-Westphalia. The Detmold-based firm Demold Jowat SE makes the glue adhesives used in the wood materials, and the third partner is Hanses Sägewerkstechnik GmbH & Co. KG. It is a wood processing specialist based in Meschede, in the Sauerland region, and is tasked with making the tools for the project.

The project is currently on schedule, and due to be completed in spring 2019. "At the moment we are in the last phase of finalising the component design. Our materials research has been concluded, and we have set up a simulation model. We also already know exactly what our components are going to look like, and now we are putting the final touches to the design," says Swetlana Schweizer, Research Assistant at the Institute Automotive Lightweight Design, Paderborn University. This means the components are now being manufactured and tested. The result will be a prototype to demonstrate the viability of wood as a genuine alternative material in automotive construction.

Lead market competition

The non-contact, automated path to lightweight components

Fibre composites are playing a major role in resource conservation through the use of lighter structural components. Yet these materials are still very expensive. The CarboLase project led by the Fraunhofer Institute for Laser Technology (ILT) aims to simplify the process chains involved, and thereby reduce costs.

There are several reasons for the high cost of composite materials based on glass fibre (GFC) or carbon fibre (CFC). First, the high cost of the initial materials themselves, secondly the large number of manual steps involved in their manufacture, and thirdly, high levels of wear and machining waste. This is the aspect addressed by a project formed as a collaboration between the ILT research institute in Aachen, the Textile Technology Institute (ITA) of RWTH Aachen University, and three partners from industry. Fibre composites are very abrasive materials, resulting in high levels of wear on drilling and milling tools, and frequent tool changes. And the conventional fabrication chain is generally prone to a high incidence of defects. "We set out to see how we could do this better", says project manager Stefan Janssen from ILT.

CarboLase is not a new fabrication technology, but rather an enhancement of the fabrication chain for CFC components, which generally looks something like this: carbon fibre mats are cut to size, then glued or stitched into multi-layer packets, and finally formed into the desired final contour outlines. These "preforms" are then impregnated with synthetic resin in the tool mould, and hardened into the desired component. This is followed by further processing, and in many cases, these components have to be combined with other elements into structural sub-assemblies. This can involve the insertion or application of threaded force application elements – generally metallic – because unlike in metals, it is not possible to cut high-strength threads in CFC materials. The practice has therefore been to drill holes for this purpose in the already hardened component. The major problem here is that machining the hard carbon fibre material causes intensive wear on the very sharp cutting edges of the tools. There is also the risk of carbon dust finding its way into the matrix and contaminating the component.

Laser rays prevent wear on the textile material

The CarboLase process intervenes one step earlier, in that the holes for threads and other force application elements are drilled in the preform, before the addition of the resin. But with a drill of the conventional type, the fibres (in the same way as other textile materials) would wrap around the drill, destroying the textile layer structure. So a mechanical contact-free fabrication process is needed – in this case, a laser. "We are using new ultra-short pulse beam sources with pulse lengths of between two and 20 picoseconds and pulse energy of up to 1 Megajoule. Within this short time, so much energy is conveyed into the material that it vaporises directly, without any thermal damage", Janssen explains. As a result, the drilling process is frictionless and reproducible.

According to Sebastian Oppitz of ITA, this makes the process much more economically viable than conventional drilling or other machining processes, such as milling. "There are big savings to be made here. Just how big we will find out in autumn, when we run some comprehensive test series," he says.

Along with the benefits of reduced wear, there will be time savings from eliminating the many tool changes formerly required. This can be a highly significant factor in the equation. In the aviation industry, for example, for safety reasons it is a compulsory requirement to use tools only up to very low levels of wear. That means correspondingly more frequent tool changes. The aviation industry also requires components to be repaired even for the most minute signs of damage. With the CarboLase process, component defects can be eliminated before they happen.

Five partners involved

The CarboLase project has a clear division of tasks between the partners. As well as leading the project, ILT is responsible for the laser technology, while ITA looks after creating the project chain. The Herzogenrath-based firm Amphos GmbH controls the laser beam source and guidance systems, and Kohlhage Fasteners GmbH & Co. KG, based in Neuenrade, contributes the bonding elements. And finally, Lunovu Integrated Laser Solutions GmbH, also from Herzogenrath, has come on board as the system integrator. The project has been entered in the lead market competition Produktion.NRW organised by the lead market agency for the German state of North Rhine-Westphalia (Leitmarkt Agentur.NRW), and will run until the beginning of 2020.

Focus on automation

Given the extensive use of manual processes still involved in the fabrication of CFC components, the researchers in the CarboLase project have also decided to focus on introducing a higher level of automation. They are therefore planning a robot cell for the stacking, forming and drilling of textile layers into packets. "The cell is designed for ultra-flexibility. We aim to use it to fabricate a wide variety of components, including flat elements and complex structures like the B pillar of an automobile", Oppitz says. "A process chain combining the benefits of automation and flexibility in this way would be something quite new".

Another new feature is the capturing of sensor data at many different points in the process chain, for use for control and adjustment purposes. This data is useful for position detection, for example, enabling the robot to detect materials that have slipped out of position. This means that it will not drill holes in the wrong position. "This is a concept we have picked up from Industrie 4.0", says project manager Janssen.

Photo: Fraunhofer ILT

Laser beam-drilled CFC preform with internal threaded sleeve.

Lead market competition

Nature as a model for lightweight design

Photos: Guido Flüchter/Fraunhofer IPT

Bionic lightweight design makes load-compatible use of fibre-reinforced plastics. The next step is to solve the challenge of laying tapes with endless fibres in a curved arrangement.

Look closely at a dragonfly's wing: despite the delicate veins and gossamer membrane, it's highly efficient and resilient. It doesn't take long to see that engineers can learn a lot from nature when it comes to lightweight design. The challenge lies in reducing the weight of components without compromising their stability.

Reduce the weight of structural components without compromising their stability: the scientists at the Fraunhofer Institute for Production Technology (IPT) in Aachen have been working on this question for more than 25 years now, optimising processes and technologies. In flora and fauna, the shapes of supporting structures do not run in straight lines, but follow power flows. Optimising materials and topology leads to the creation of efficient structures that are light but still robust.

The concept of designing supporting structures along existing power flows is something the researchers at IPT have been applying to composite fibre technology in collaboration with industrial partners from North Rhine-Westphalia. Drawing inspiration from bionics, the partners submitted their "BioStrukt" project idea to the Produktion.NRW lead market competition in NRW, the results from which should enable the manufacturing industry in NRW to make load-compatible use of fibre-reinforced plastics (FRP) through the use of bionic lightweight design, saving raw materials and thus costs.

In Fraunhofer IPT's Lightweight Design Production Technology business area, FRPs are designed to be load-compatible using IPT's own "PrePro" tape applicators. This makes it possible to produce components that are extremely stable but very low-weight. Using the technology that is currently available, manufacturing bionic structures from endless fibre would not be economical, even with high resource efficiency, and so potentials for weight reduction and even more efficient use of materials remain unused. The challenge is therefore to lay the impregnated fabrics (fibre-reinforced tapes) with endless fibres in a curved arrangement to reflect the load distribution.

The multidisciplinary "BioStrukt" project (bionic lightweight design through the economical manufacture of structure-optimised lightweight components with directed fibres) is intended to achieve this goal. The result should be a manufacturing process that follows nature's example in laying the fibres not in straight lines but in a curve along existing power flows. It will create FRP components that are optimised in terms of topology and material, with input from the thermoforming and back-moulding technology fields.

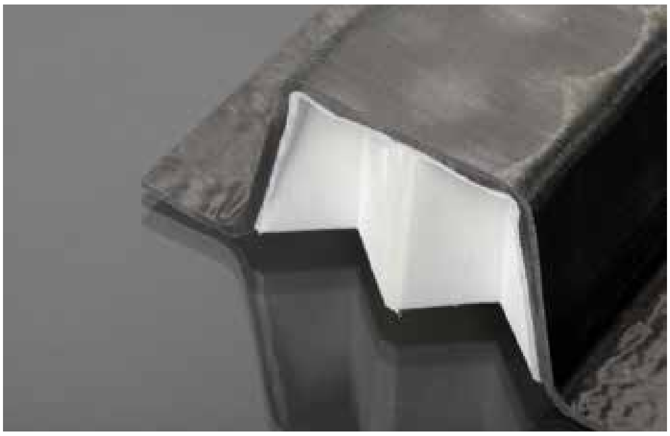
The research project aims to refine the process of automatic tape laying using the PrePro tape applicator to permit thermoplastic tapes made of unidirectional endless fibres to be laid in curves. This should produce load- and waste-optimised organic sheets. After forming, the semi-finished products are back-moulded using an injection-moulding process, which can enable the components to function as attaching devices, for example.

Along the process chain, the semi-finished product passes through different states, from solid to non-rigid, heated and shaped. The novel anisotropy of these semi-finished products also raises a number of questions. Current gripping technologies reach their limits when dealing with them, for example. The planned project must therefore investigate how to handle these semi-finished products, so these technologies can be linked with an integrated process chain. At the end of the process chain will be a technology demonstrator that will illustrate the benefits of bionic lightweight designs, in the form of a completed rather than a semi-finished product.

The research project will also incorporate data to create a digital shadow of the bionic FRP product. This involves networking the individual processes at a virtual level to form a process chain. Integrated measurement processes enable continuous quality monitoring, so defects occurring during the tape-laying process can be recorded and identified. Real-time feedback will continuously optimise the process and improve process safety.

Developing the manufacturing process will draw on the knowledge gained from the LightFlex project, which was sponsored by the German Federal Ministry of Education and Research, in which a process chain was developed for the cost-efficient production of individual hybrid components made of FRP and 3D printed elements: the forming process for fibre-reinforced plastics guarantees component stability, and 3D printing makes it possible to create the forms and functions with maximum flexibility.

An automatic photonic process chain has been developed that can be used to manufacture individual products from FRP with integrated functional elements flexibly, quickly, and cost-effectively. This can be used to produce FRP prototypes such as customised seat buckets for vehicles, or artificial limbs with individually adapted fitting systems.



Combination: fibre-reinforced plastics in combination with additively manufactured elements develop particular properties. The shaping process guarantees their stability. 3D printing allows for flexible manufacturing processes.

Tapes with endless fibres: the load-optimised arrangement of components helps to keep the overall weight down.

Truss structures for optimum lightweight construction

ANSGAR POLLEY

Topology optimisation is undergoing a revival thanks to the possibilities opened up by additive manufacturing. Based on the available installation space, material is removed from exactly those places where it has least effect on the functionality of the component. Using simulation applications from Cadfem GmbH, products can be optimised virtually, before they are produced.

Photo: oonal/iStock

Evolution provides the model for framework structures; this image shows the variable microstructure in a bone.

Topology optimisation results in component structures reminiscent of forms that have developed organically. Tree branches or bone structures evolve into efficient designs according to the loads they are subject to. This evolution can be transferred to product development in an accelerated manner using design algorithms.

Topology optimisation: As well as the installation space and the loads, it is also possible to define the optimisation objectives and constraints. As optimisation objectives, pliability, stiffness, natural frequencies, volume and mass can be minimised or maximised, taking into account any constraints. Thus, for example, topology optimisation may be specified to achieve minimum pliability with an 80 percent reduction in installation space, or minimum mass with a given pliability of 0.05 mm. Specified constraints might include symmetry, minimum or maximum structure size, or the demoulding direction of moulded parts.

Optimised component designs

During the analysis, which is performed on computers typically used for CAD, material is eliminated gradually, so that the progress of topology optimisation can be directly observed. As a result, the designer receives an optimised design proposal that fully meets the given requirements. This is available not only as a three-dimensional representation, but can also be used directly as a CAD model. Additional functions for smoothing the geometry and melding with connecting components are also available. While the optimised component designs can also be produced by conventional methods, they are predestined for additive manufacturing due to their organic shapes.

Lattice optimisation: Thanks to the layered construction technique used in additive manufacturing, it is possible to realise even the most complex geometries without additional effort, enabling the cost-effective production

Graphics/Photo: Cadfem

Left to right: traditional design, topology-optimised design, and a gripper produced using additive manufacturing.

of components that are close to optimal in terms of loads. This manufacturing advantage systematically opens up the possibility for a further degree of freedom in component geometry. Similar to the structure of bone, in which the density is able to adjust according to load paths due to its variable internal structure, the internal structure can also be made variable in technical products that have high demands on the lightweight construction potential.

Structures correspond to the load paths

The fine structure consists of a framework (lattice) for which the dimensioning (density of the nodes, strength of the truss elements) is defined by the load paths. Accordingly, the outer shape of the inner structure providing the stiffness can be separated from this function, and designed according to different criteria. For example, for motor sport chassis components, the internal structure of the lattice can follow the load path in terms of rigidity, while its outer shape can be designed according to flow aspects. Similarly, in the food processing industry for example, external shapes that are easy to clean can be combined with load-optimised internal structures.

Enclosing the structure providing the stiffness increases the acceptance of seemingly unfamiliar topologies and protects against counterfeiting of innovatively developed components.

Process simulation: Not only do simulation tools result in optimised component geometries; they also provide quality assurance in demanding manufacturing processes. Additive manufacturing in particular, which in principle produces a finished component with only one weld seam, creates new demands in terms of knowledge and experience – expertise which can be ideally complemented using simulations. The melting, cooling and shrinking of material, the layered construction technique and mechanical and thermal influences on support geometries all combine to create a large number of factors that have a major impact on quality. This results in uncertainty regarding the achievable dimensional accuracy and the adjustable microstructure (e. g. density and framework), as well as doubts about which process parameters to select.

The process is determined by many factors

Simulations can help eliminate these uncertainties and identify appropriate process parameters. In addition to the pressure parameters, the choice of a suitable support geometry is an important influencing factor. Not only do these geometries support overhanging parts of the component, they also have a thermomechanical effect, ensuring local heat dissipation.

These support geometries can be generated automatically, for example with variable spacing or variable wall thickness. In addition, it is possible to compensate for the calculated and unavoidable component distortion through adjustments to the geometry, so that a high dimensional accuracy can still be achieved with this production process. Process simulation also helps to avoid misprints. The quality of components produced through additive manufacturing is increasing.

When all three elements – the topology optimisation of the outer shape, the lattice structures that determine the internal fine structure, and the additive manufacturing process simulation – are considered together and coordinated with each other, this results in a design for additive manufacturing (DfAM). To use this methodology in the design and product development process, the individual process steps need to be closely interlinked and integrated into a logical workflow. This enables us to combine engineering knowledge, simulation technology and manufacturing expertise, to take lightweight construction to a new level.

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Hollow profiles instead of sheet metal

BORIS KOCH AND LUKAS SCHRÖER

Plastics/metal hybrid technology is an established construction method in structural lightweight design. It deliberately combines the strengths of sheet metal and plastics. Extending the hybrid technology to include the use of hollow metal profiles with round and angled cross-sections considerably increases their performance.

Photos: Lanxess

Pedal box made using hybrid technology: thin sheet profiles are reinforced with polyamide in the injection moulding tool.

Plastics/metal hybrid technology was developed and taken to the series production stage by Lanxess AG for lightweight design purposes. It is used to manufacture vehicle components that are subject to heavy stresses – front ends, for example. Other applications are pedal boxes, brake pedals and roof frame structures. The injection moulding component used is generally glass fibre-reinforced polyamide 6, with steel plate as the metal component.

A hybrid design often has clear advantages over metal-only solutions – for example, those based on multiple preformed and welded steel plates. Simple metal profiles can be used, and costly metal processing stages can be omitted. There is, accordingly, no need for forming tools.

The components can be shaped with complex geometries using thermoplastic polyamide 6. Compared to open, metal-only structures, their mechanical performance is superior when it comes to torsion stiffness and strength. And compared to steel-only solutions, not only are they up to 40 percent lighter, but they can also be manufactured up to 50 percent more cheaply. Aluminium plate can also be used, resulting in further weight savings.

Tailored for structural components

Hybrid technology has now reached another stage of development. It has been extended to include the use of hollow metal profiles with round and angled cross-sections. This is the result of work performed in the Centre for Product and Application Development in the High Performance Materials business unit of Lanxess in Dormagen, North Rhine-Westphalia.

Compared to open sheet profiles, hollow profiles have much greater dimensional stability and offer higher torsion stiffness and torsion strength. We can therefore assume that this new method, known as hollow profile hybrid technology, will be used in future to manufacture components such as dash-

Compared to a hybrid component based on sheet steel, the hollow profile hybrid demonstrator has much greater dimensional stability, with better torsion stiffness and torsion strength.

board supports, which cannot be made rigid and resilient enough with the traditional hybrid method used to date.

Simple manufacturing process

For the hollow profile hybrid technology, Lanxess developed a simple, one-stage process. First, a number of solutions had to be found: for example, it has to be easy to fit the metal insert into the injection moulding tool. The production process creates tolerances that can damage the tool and – if the inserts are too small – can prevent the tool from fully sealing. The insert must also be supported to enable it to resist the high pressures of molten masses during the injection moulding process, without being compressed. The polymer and metal must also be firmly and permanently bonded in all directions.

The result of the development work is a process that is suitable for mass production, requires only minimal investment in plant, and is almost as simple as the traditional hybrid method using sheet metal. A key benefit is that the procedure involves no additional steps that would prolong the familiar short processing times associated with injection moulding. The same sort of short cycle times can be used in manufacturing as are typical of injection moulding for mass production.

Test piece and tool constructed

To put the new technology to a practical trial, a test piece was designed and a tool constructed to make it. Bonds between materials and bond tightness can be investigated using the test piece. It is structured for demonstration purposes and for component trials, and gives interested parties an opportunity to test the great stability of the bond for themselves. The test pieces proved that the process works as intended during the design stage.

Broad application in mechanical engineering

Besides dashboard supports, hollow profile hybrid technology offers great opportunities in making other structural components that are subject to major mechanical stresses. Conceivable applications in lightweight construction for the motor industry, for example, are seat structures, front ends, tailgate supports and mirror supports for goods vehicles. It also offers good opportunities for use in the manufacture of furniture, ladders and children's pushchairs.

Lanxess also offers customised polyamide compounds as injection moulding materials for use in hollow profile hybrid technology. It makes them at its plant in Krefeld-Uerdingen. They include particularly easily flowing material variants for complex rib structures and geometries, and highly filled forms of polyamide 6 with up to 60 percent glass fibre, which further enhance the mechanical performance of hybrid components thanks to their high strength and stiffness.

Inserts for die-casting and extrusion systems

Research is in progress to find ways to extend hybrid technology to include simple, low-cost inserts for die-casting and extrusion systems. The new hybrid technology is also compatible with hollow-profile inserts made of fibre-reinforced materials. This could lead to further weight savings in the series production of structural components.

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Using laser light to master lightweight construction

Many joining and cutting processes were not possible until the use of lasers. For instance, thanks to new technologies, metal components with hollow structures can be manufactured, which are significantly lighter but just as stable as solid components.

Photos: Fraunhofer ILT

Processing methods using light: The laser combi-head is used for cutting and welding steel, as well as for additive manufacturing. The hybrid laser beam source consists of a diode laser for heat treatment and a fibre laser for cutting.

Lightweight materials are popular. Aluminium is used in car bodies. New aircraft fuselages already consist of 50 % of lightweight components made of carbon fibre composites. New production or processing methods accelerate the manufacturing process and make materials lighter and more stable. Laser technologies contribute to this in a special way. The Fraunhofer ILT develops metallic components and produces suitable prototypes, which are weight-optimised thanks to a special internal structure. The Fraunhofer Institute for Laser Technology ILT in Aachen researches developments, from automotive engineering to aircraft and medical technology, with the aid of laser technology.

Researchers at the Fraunhofer ILT are specialised in the production of metal components with comparable lightweight structures. The advanced Selective Laser Melting (SLM) process, the main features of which are similar to 3D printing, is used for this purpose. Using a laser beam, powder is precisely melted according to CAD data and cured to micrometre-thin layers.

Lightweight and stable

The component grows, layer by layer. The researchers have developed, among other things, a very light and stable wishbone suspension for a sports car using the SLM method, from which the wheels are suspended individually. This wishbone suspension also has a hollow structure inside. That makes it lighter and more stable than cast or machined components. The complex hollow structure could not be realised without the SLM process.

Bonding without adhesives

Making components or vehicles lighter and lighter is also a challenge in terms of functionality. Weight reduction cannot be at the expense of stability. That is why different materials are often combined in lightweight construction, which are best suited for various applications – aluminium or fibre-reinforced plastics (FRP). The different materials are usually bonded to one another nowadays, since the stability of FRP is reduced when bolted to other components.

But with the adhesive, a third material enters the process. The disadvantages of using an adhesive are that it may start an aging process and that it may become brittle. Because of these disadvantages, ILT scientists rely on laser-based processing methods for joining FRP and metal. In this case of a hybrid connection, they use the laser to burn a 100-micrometre fine pattern with small grooves and undercuts into the surface of the metal component. "When metal and FRP are joined, the hot and liquid plastic flows into the grooves," explains ILT laser expert Dr Alexander Olowinsky, "so that the plastic grips into the metal surface when it hardens."

Types of steel in combination

Not only FRP and metal are more and more combined. Depending on the application, different types of steel are also joined in a special way. To reduce weight, car manufacturers are using, among other things, press-hardened, high-strength steel. Such steel is exceptionally stable, so that thinner metal sheets can be used.

Even though this results in weight reduction, such steel is expensive, and its use must therefore be limited to the necessary areas. In cars, conventional steel and press-hardened, high-strength steel are therefore used side by side and welded together.

The usual processes, such as spot welding, result in less stability of the high-strength steel at the welding point. In a cooperation project between the Fraunhofer ILT and several industrial enterprises, an alternative welding process was developed to join conventional and high-strength steel. This innovative process does not compromise the crash stability of high-strength steel and facilitates the use of both types of steel.

Laser cutting with tracking heat treatment laser. Local heat treatment can improve the crash properties of components by imprinting softer zones.

Lightweight truck seat with 20 kg weight saving at the top. The seat support made of glass fibre-reinforced plastics developed at the Fraunhofer ILT contributes to this.

Series production of fibre-reinforced plastics components

KAI FISCHER

Lighter and more functional: those are the demands being made of plastics components. Not only in the automobile industry – low component weight is an advantage in almost all applications and in all industries. Saving on materials is synonymous with curbing costs and conservation of resources. Lightweight components can be achieved using a range of procedures and a variety of combinations of plastics, fibres and semi-finished products, as well as metals.

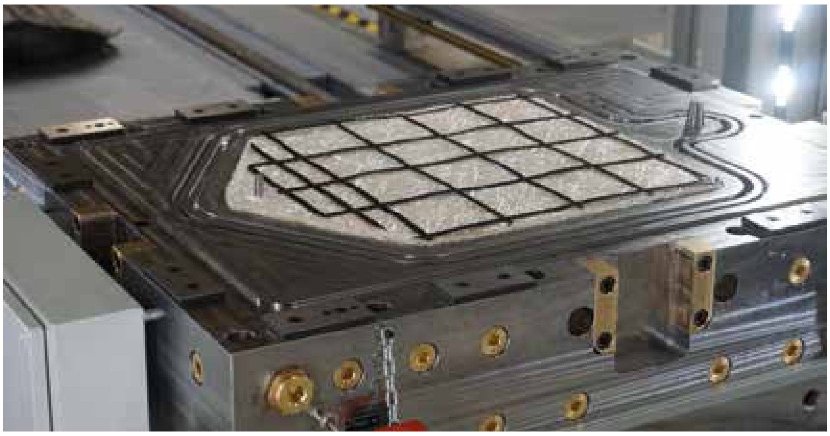
Photos: IKV, AZL

A self-regulating production plant makes it possible to maintain defined properties of composite components.

The multidisciplinary project iComposite 4.0 is aimed at achieving the commercially feasible mass production of components using fibre-reinforced plastics by improving resource efficiency. As well as the press manufacturer Schuler AG, the partners in this project (sponsored by the Federal Ministry of Education and Research) are the Aachen Centre for Integrative Lightweight Production at RWTH Aachen University, Apodius GmbH, Broetje Automation Composites GmbH, Frimo Sontra GmbH, ID-Systec GmbH, the Institute of Plastics Processing (IKV) in Industry and the Skilled Crafts at RWTH Aachen University, Siemens AG and Toho Tenax Europe GmbH. Apodius has developed optical measuring systems to identify fibre orientation. Teijin Carbon Europe GmbH, of Wuppertal, creates corrective methods to offset fluctuations in the composite fibre material and manufacturing process.

Because of their very good weight-specific mechanical properties, fibre-reinforced plastics (FRPs) are of great interest for use in lightweight design applications for the automobile and air transport industries. But the world of component manufacture is still dominated by complex and cost-intensive manufacturing processes that are characterised by a low level of automation, inefficient use of materials caused by waste and high reject rates, and high component costs. In turn, this means a high potential for productivity increases, which must be achieved by digitalising production and networking production machinery. This is the objective of iComposite 4.0. The project pursues the approach of building up an intelligent, self-regulating production system for the commercially feasible mass production of FRP components. In addition to increasing productivity, it aims to achieve a cost saving in the order of 50 percent.

The basis for this resource-efficient production system is the 3D fibre injection moulding process developed at IKV. This involves cutting endless fibres (fibre rovings) to the desired length automatically and with a high volume throughput, aligning them, and applying them to a complex layering tool. The procedure is able to manufacture a preform with a high level of productivity, with no wastage of costly semi-finished fibre products or labour-intensive draping processes, to closely approximate the final desired contour and incorporate the load paths typical of the component.


The object of the multidisciplinary project iComposite 4.0 is to achieve commercially feasible series production of components using fibre-reinforced plastics by improving resource efficiency.

Targeted offsetting of fibre distribution

To enable the 3D fibre injection moulding process to be used effectively in series production – despite possible fluctuations in terms of fibre orientation and surface weight – it has been incorporated in a self-regulating production system. Inline monitoring of fibre orientation and distribution in every preform enables the fluctuations to be offset using endless fibre inserts. The result is a quality-assured component with constant mechanical properties, despite the individual semi-finished product properties, following customised impregnation for each preform.

The networked production system begins with 3D fibre injection moulding, which is used to create the basic structure of the component. Fibre strands are then applied with great precision to take account of the relevant stresses, to pick up the peak loads in the component and at the same time offset the fluctuations in component properties created by the fibre injection moulding process. The subsequent stages of resin injection and forming in the press then influence the deflection of the tool to achieve the desired component wall thicknesses. The manufacturing history is stored in an RFID chip integrated into the component.

Other research projects at IKV on the subject of lightweight design involve describing and making targeted use of the material behaviour, weight and property-optimised simulation and component layout, the use of the right production technology, and the repair and recycling of lightweight components.

From material testing to foam manufacture

The mechanical properties of fibre-reinforced plastics, their fatigue behaviour and creep and relaxation behaviour all play an important role in the various applications. To be able to estimate these values, IKV is investigating the property profiles of FRPs with short and long fibres, and is constantly optimising the measurement process.

A new opportunity to characterise fatigue performance is provided by tests on pre-series test pieces. These are less costly than the fatigue tests traditionally performed on real components, and provide characteristic data for a given material independently of the component. An inclusive method of calculation is recommended to estimate the long-term behaviour of fibre-reinforced components that use long fibres, in particular. This method consists of an interface to link a filling simulation using the principles of flow mechanics to a simulation based on structural mechanics, and of a material model developed in-house.

Foams are also used in lightweight design applications. These are produced in a range of processes using different materials. One approach involves physically foaming polyurethane (PUR). This is a polymer used in padding, in shoe soles, and in sandwich cores. The most suitable method in this case is the cost- and material-efficient procedure of physical foaming using carbon dioxide. Another approach involves the chemical foaming of thermosets using injection moulding, which is the object of a research project begun last year. Thanks to their high temperature resistance, lightweight thermoset components offer huge potentials for automobile applications. The initial results show that they can be used to manufacture components, and that weight reductions of up to 20 percent can be achieved.

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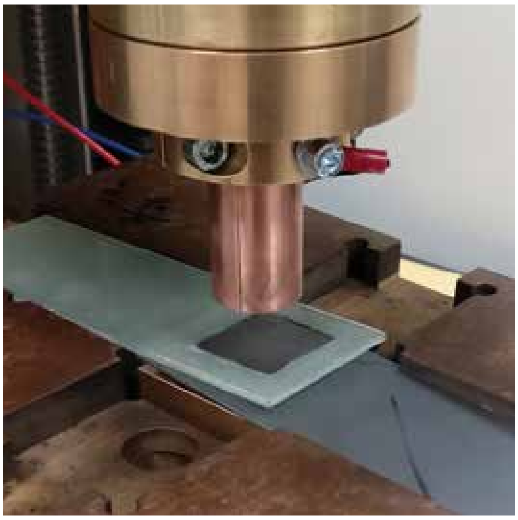
Hybrid components can be welded

UWE REISGEN AND JENS LOTTE

Demand for hybrid components is picking up quite substantially, since the combined properties of plastics and metal are particularly well suited for use in lightweight design strategies. An innovative procedure should make it possible to weld metals and fibre-reinforced plastics. Examples of application are structural components for the aircraft industry (vertical stabilisers, engine cowls), and cowl elements for automobiles (side panels, rear spoilers) and utility vehicles (bonnets, raised roofs).



Welding an inserted hybrid test piece on a capacitor discharge welding system.

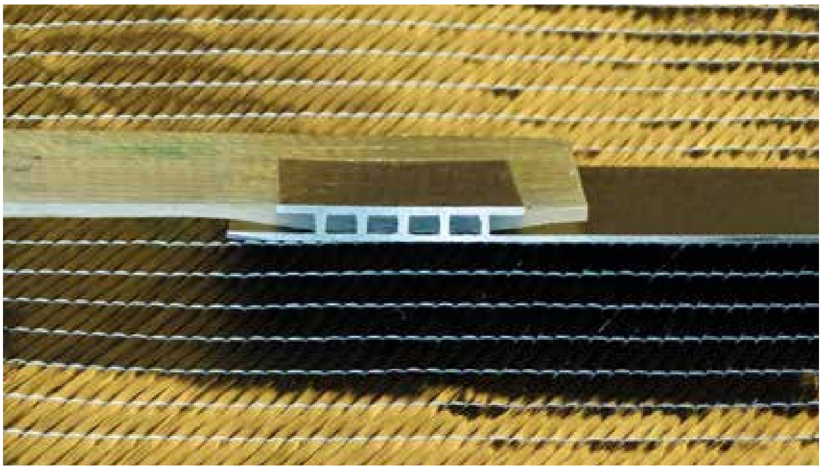
Hybrid test pieces made of fibre-reinforced plastics and steel can be welded on an appropriate welding system using a support for the test piece made of synthetic resin bonded paper.

Photos: ISF

There are technical challenges to joining fibre-reinforced plastics (FRPs). It is very common for bonds of thermoset FRPs and steel to be glued. Gluing processes, however, require labour-intensive surface pre-treatment and fixing strategies. These additional processing stages make the overall process longer. The lengthy curing times required for many adhesives are also problematic.

This type of bond can also be produced using mechanical joining technology. Mechanical joining methods such as screwing or semi-hollow punch riveting cause significant damage to the reinforcing fibres, however, which in turn impacts on the strength of the component. As a consequence, FRP components have to be overdimensioned at the point where they are joined. This is not a suitable procedure from the perspective of lightweight design. Although various approaches have been tried for the manufacture of plastics-metal hybrids, there is still a need for a joining process that meets the technical and economic challenges involved in combining metal and FRP.

An innovative approach being investigated by the Institute for Welding and Adhesion Techniques (ISF) at RWTH



A finished welded hybrid test piece can be seen in cross-section.

Aachen University is based on the integration of metallic inserts into the FRP during non-critical cycle times in semi-finished product manufacturing processes. This enables the component to be processed locally using conventional welding methods. There are four steps to this joining process, starting with attaching pins to a base plate. One possible procedure here uses the Cold Metal Transfer (CMT) Pin from Fronius International GmbH. This procedure is suitable at a laboratory scale given its great flexibility in terms of pin geometry and arrangement, and its good quantitative scalability.

CMT pin welding is an arc-welding process. Pins are welded onto a base plate using controlled electric pulses. During FRP production, this base plate is integrated into the semi-finished product, which allows for metal-to-metal contact. Once the resin cures, the part can be welded to a connecting metal component using conventional resistance welding.

Component strength under testing

Tension-shear test pieces are produced and tested to demonstrate the strength of such components. Once 21 pins have been welded, the base plate is integrated in the FRP manufacturing process, resulting in an FRP component capable of electrical contact on both sides. The metallic side uses steel in grades 1.0330 and 1.4301 as base plates and joint plates; the pins consist of steel in grades 1.5125 and 1.4306. The FRP components are manufactured at the Institute of Plastics Processing (IKV) in Industry and the Skilled Crafts at RWTH Aachen University. Capacitor discharge welding was selected as the form of resistance welding used, since the short process time involved causes very low heating of the metal insert and thus of the plastics. This is particularly important to avoid heat damage to the plastics during welding.

The series of tests using steel combination 1.0330 as the base and joint plate achieved tensile shear strength values of 10 kilonewtons with the unidirectional fabric, and 9.7 kN with the atlas tissue. The strength of the other combinations using steel 1.4301 as the base plate was ten to 20 percent lower.

Joining process with plenty of freedom of design

Overall, the trials confirm the great potential offered by the new procedure in the area of joining different materials, in this case metals and FRP. The project is sponsored by the Federal Ministry of Economic Affairs and Energy via the German Federation of Industrial Research Associations, as part of the programme for the funding of industrial collective research (“IGF”).

The joining procedure offers many opportunities in terms of freedom of design in the joining zone, since the layout, number and geometry of the pin structures can be flexibly adapted to suit different requirements. The procedure can be used to achieve a separation in terms of time and process between manufacture of the semi-finished products and the joining process itself. Conventional welding processes can be used. Medium-frequency DC welding can also be used in addition to capacitor discharge welding. The trials already demonstrate high static bond strength values, which can be increased by coordinating the welding parameters and component geometries.

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New carbon composite technique helps in the drive to reduce weight

MICHAEL METZLER

A new approach to carbon composite manufacture could finally enable the material to break into series production automotive applications. The demand for lightweight materials to improve CO_2 emissions, as vehicles become heavier and more complex, has never been greater but the cost of composite manufacture has remained unaffordable in all but the most specialist niche applications.

Photos: ZSK Stickmaschinen

The automotive industry likes lightweight materials. Layering and embroidering machines allow custom-fit and material-efficient design using fibres.

The problem is the raw material. Most composites begin as a sheet of woven fabric which is cut into preforms, laid up in a mould and impregnated with resin. This condemns all the fibres to be arranged in two directions, at 0 and 90 degrees, and to take the form of a rectangle. For many applications, there is huge wastage and the action of cutting to shape means that the remaining fibres are often not arranged in the best way to carry the loads present. This leads to the addition of further layers, with their fibres in the preferred direction, making the finished part heavier, less efficient and more wasteful, increasing the cost.

TFP: a new approach that puts the fibres where they are needed

To overcome these issues, a new approach to composite manufacture, called Tailored Fibre Placement (TFP) has emerged from the embroidery machine industry. Instead of weaving all the fibres into a perpendicular arrangement then cutting to the required shape, the functional fibres are arranged in bundles exactly where they are most needed for structural performance and stitched into position on a compatible textile or polymer base layer. Production is entirely scalable through the addition of more multi-head layering and embroidering machines.

A key advantage of TFP is that, through selective stitching, it provides absolute freedom of positioning, ensuring that the fibres do not move during processing and yet still permitting the preform to be folded where required. This means that, for the first time, a complex carbon composite 3D component can be produced economically and consistently, with low cycle times. The ability to vary the stitching properties locally means the preform can be stretched, bent or folded without wrinkling. Furthermore, fibre wastage is only 1-2 % of the total.

Julius Sobizack from ZSK Stickmaschinen GmbH, a Germany-based TFP layering and embroidering machine manufacturer, says that TFP is the gateway to greater carbon composite design freedom within the automotive sector. Tailored fibre placement allows complex 3D shapes to be created from a 2D preform in a quick and consistent way, with a lower cost structure. It unlocks significant design potential.

The equivalent in sheet metal working would be the hydroforming of tailored steel blanks with variations in section where reinforcement is required. The production of a 3D shape from the 2D tailored blank is analogous to the moulding of the composite preform to create the finished part.

The benefits of being able to lay the fibres in the direction of load, instead of cutting across the fibres of a pre-woven sheet, have been clearly demonstrated in tests on components with holes; TFP allows the fibres to be laid around the hole. Under tensile testing, instead of failing at the hole in the usual way, the part fails as though no hole was present and withstands up to 50 % higher load before failing.

Achieving cost-competitive manufacturing through automation

The improvement in production rates and consistency is equally marked, helping composite manufacturing to compete more effectively with sheet metal. CNC-controlled TFP machines are available with multiple heads so, for example, in the time it takes to make one preform an eight-head machine can make eight preforms, and large, multi-head TFP machines can often be installed for less than the cost of a typical automotive sheet metal forming tool. One ZSK head can lay between one and three kilograms of preform per hour, and can handle two rovings of up to 60,000 fibres each.

With scalability using multi-head machines and no requirement for complex cutting table technology, TFP is a cost-effective way into the composites market. Automation helps not only the economics of manufacture but the efficiency and quality of the design process. The growing use in the automotive industry of biomimetics to produce optimised structures by mimicking nature requires the load-bearing fibres to be distributed in exactly the right orientations to carry the principal stresses. Advanced software packages are available that can convert the preferred component topology established using an FE (Finite Element) solver into a stitching pattern that combines optimum fibre placement with good manufacturability.

Improved recycling

The use of thermoplastic polymer to create the matrix in a TFP composite overcomes the recycling difficulties of conventional composites that use thermoset resins. Whereas the thermoset materials cannot be melted out, the thermoplastic content can be readily separated as it melts at around 200 to 300° C. Due to near-net shape production, less manufacturing waste material is generated and this reduces the need for recycling at the production stage.

Technical embroidering machines allow radial and axial design of fibres according the flux process that has been defined in the component.

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Lightweight design in mass production using wet compression moulding

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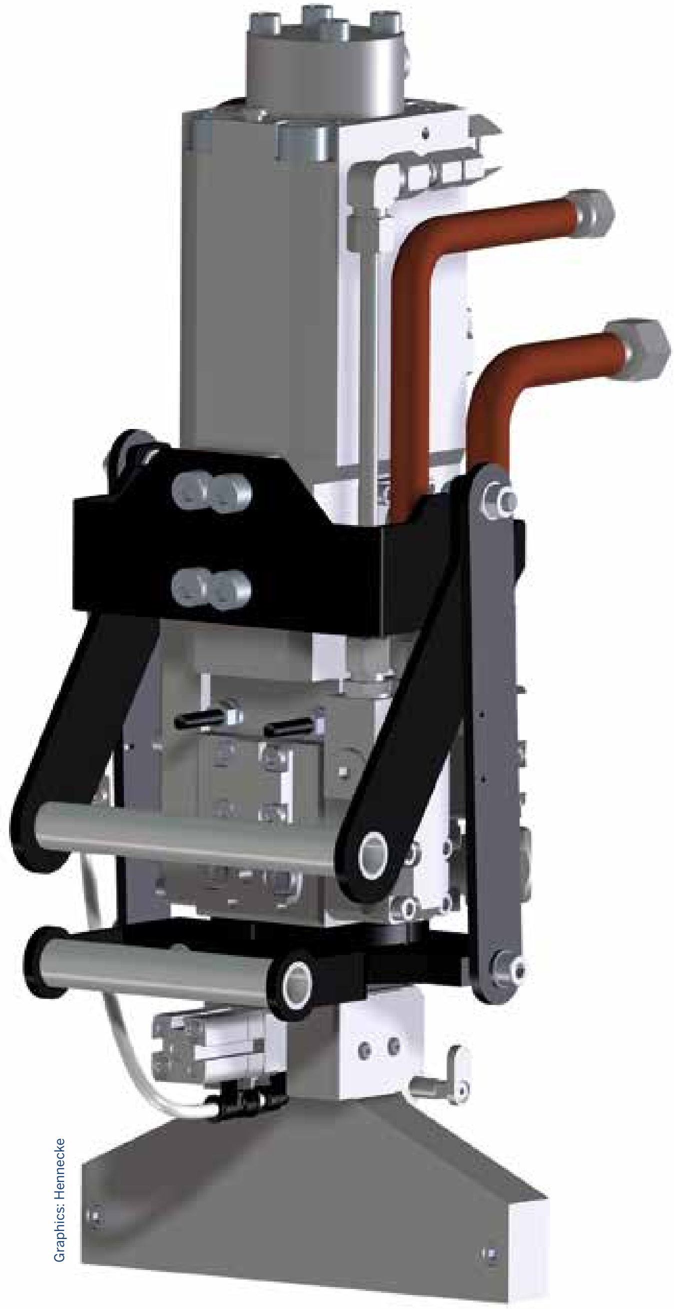
Lightweight design is finding its way into small-scale and mass production in the automobile industry. The emphasis is on innovative plastics components. There is hardly any other product category in which so many new processes have developed in such a short time. The lightweight design specialists at Hennecke GmbH have made improvements to wet compression moulding technology to deal with these tasks.



Graphics: Hennecke

Wide-slot nozzle for wet compression moulding: this production method is suitable for series production of fibre-reinforced structural components. The reactive mixture is applied to the fibre roving as a fluid film. This is done either using robot-guided application, or directly within the tool.

Making full use of the range of properties offered by different plastics is leading to entirely new processing methods for the manufacture of automobile components. Users are encouraged to take a proactive approach to lightweight design in automobile manufacture. Hennecke uses wet compression moulding (WCM) technology to support high-volume production of fibre-reinforced structural components.

To accommodate a wide range of demands, key improvements have been made to wet compression moulding. WCM technology is an efficient production method for high-volume production of fibre-reinforced structural components. It involves applying the reactive mixture to the fibre roving contactlessly as a fluid film. This is done either at a separate work station using robot-guided application, or directly within the tool.

Dosing machines offer a custom-fit processing system for all current matrix systems of fibre composite components. The modular construction conforms to production needs and becomes integrated in automated production lines.

In the separate work station, the fibre roving is guided by one or more robots below the WCM nozzle in the mixing head. The reactive mixture is then applied to the fibre roving, and the robot then positions the impregnated roving perfectly in the tool. The press, together with the tool, then closes and ensures the reactive polymer is evenly distributed. Once it has cured, the component can be removed for trimming.

When WCM technology is used with complex geometries or large components, the material can be applied directly in the lower die. In such cases, the lower die is typically removed from the press to ensure maximum accessibility. Once the material has been applied, the tool is returned to the press, which closes and the curing process begins.

Hennecke developed the WCM nozzle with wide-slot geometry with an eye to fast and easy maintenance. As a result, it can be positioned by a single operator in a matter of seconds – or replaced if maintenance is required. The wide-slot nozzle is positioned in angle increments to ensure reliable reproducibility. This single-user maintenance approach also served as a model for the development of a new mixing head for rapid colour changes in the field of component surface treatment. The nozzle has given the lightweight design method a new boost. It differs from previous nozzles thanks to its improved wide-slot geometry, and also offers additional safety functions.

One benefit with the nozzle is in retrofitting: it can be fitted to all HP-RTM mixing heads of the latest design currently on the market. As a result, laboratory facilities can be expanded to include the latest technology using the WCM functionality. The WCM technology is much less demanding on the production process than the HP-RTM process, for example, in terms of the complexity of the moulding tool.

Processes in combination

Production systems can be combined for wet compression and HP-RTM applications. The HP-RTM process works with high-pressure machines and is fitted with RTM mixing heads. The combination of both processes makes rapid series manufacture of large lightweight components possible, for electric mobility, for example. One option is for a combined plant to be fitted with two mixing heads. The first is used as an HP-RTM mixing head and is attached to a tool inside the press to inject the reactive raw material directly into the tool and infiltrate the fibre roving. The second mixing head is fitted with the wide-slot distributor. It is controlled by a robot to enable the automatic application of resin onto the fibre roving outside the press. The two mixing heads make it possible to switch between the two technologies with only a short changeover time. As a result, different fibre composite components can be produced using the same plant. The HP-RTM process is ideally suited for the manufacture of complex 3D components, while wet compression moulding is used in the efficient manufacture of large and less complex fibre composite components.

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