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Image: EOS is a pioneer in the field of direct metal laser sintering (DMLS). It also provides polymer technology and is now distributing in Europe two fiber-reinforced polymers for AM from ALM, a wholly owned subsidiary of the company.

REINFORCED *plastics*

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RP Rewind

Liz Nickels leafs through past issues of Reinforced Plastics to find out what was happening in the RP industry of the past.

Five years ago...

Freelance journalist George Marsh took an in-depth look at the growth and potential of thermoplastics in the world of composites – ‘a beguiling technology that look set to take a growing share of the reinforced plastics market,’ he said. ‘Many see this material class as the future wave in composites, envisaging everything from rapidly thermoformed structural parts for electric cars to impact-resistant leading edges on fast-moving aerodynamic surfaces. Some see it as being the ‘missing link’ between exotic top-end applications and the mass market.’ However, as he explained, thermoplastics were up against similar constraints to those faced by thermosets when competing with metals. ‘By now there is a considerable body of experience over a wide application base and growing designer confidence in the use of thermosets, enabling these composites to displace or partner metals. But this was not always so and TPCs face those same barriers that thermoset composites have largely overcome.’

Meanwhile, Composites Europe taking place in Düsseldorf, Germany, this October, was set to post record attendance numbers, with around 440 exhibitors from 25 countries expected – compared to a total of 406 exhibitors, but from 28 countries, welcomed at the 2017 exhibition.

10 years ago...

This issue talked about the emerging market for ocean energy – wave and tidal power. ‘There are numerous concept tech-



According to editor Amanda Jacob, the UK is forecast to be the biggest market for ocean energy.

nologies for devices to capture energy from the ocean's movement,’ said editor Amanda Jacob. ‘Although it's early days for this sector, commercial activity is now increasing and could develop quickly. The UK is forecast to be the biggest market for ocean energy – it has excellent wave and tidal resources and is home to a large number of wave and tidal device developers – with the USA in second place.’

Overall US domestic production of glass fiber reinforced composites had been falling steadily in recent years, according to a report from The American Composites Manufacturers Association (ACMA). In 2008 production stood at 1.38 billion kg as opposed to 1.86 billion kg in 2005, with the construction and marine sectors the

hardest hit. However, demand for glass fiber reinforced composites in wind energy, aerospace and corrosion markets continued to grow.

Meanwhile, US demand for reinforced plastics was forecast to grow 2.8% annually to reach 3.6 billion lbs in 2013, giving a market valued at US\$7.4 billion to create a market for 2.3 billion lbs of resin and 1.3 billion lbs of reinforcements, according to a report from US market research firm The Freedonia Group Inc.

20 years ago...

One of the first applications of reinforced plastics in automotive was the Tiga, designed and built by Tiga Racing Cars

Ltd, Reading, UK, with a body constructed in glass reinforced plastics (GRP) from Strand Glassfibre. 'Without reinforced plastics small volume racing manufacturers like ourselves just would not be financially viable,' explained Howden Ganley, Tiga's managing director. 'If we were using metal we would need to have a whole

range of tools and dies. The material is ideal because it combines strength with lightness and can be easily fashioned.'

In other news German piano manufacturer Wilhelm Schimmel Pianofortefabrik GmbH developed an innovative grand piano featuring a cabinet made from glass reinforced plastic (GRP) in collaboration

with industrial designer Luigi Colani. The Pegasus piano's cabinet is made from GRP filled with a polyurethane foam and encased with a special gel-coat that allows it to be sanded and finished with a lustrous lacquer coating.

1369-7021/<https://doi.org/10.1016/j.repl.2018.06.037>



Applications

Approval for bio-based resins

Sicomin says that it has now received the ECOBOARD Project Gold Level qualification for its range of bio-based epoxy resins.

The certification applies to Sicomin's entire GreenPoxo range that now consists of five different resin systems.

The ECOBOARD Project is an independent third-party consumer-facing certification program for surfboards, designed and managed by environmental non-profit Sustainable Surf. The program's focus is on helping board builders to use more sustainable materials and technologies. ECOBOARD Gold Level is reportedly the latest and more stringent certification and all of

the components in boards labelled ECOBOARD Gold Level must consist of ECOBOARD-qualified materials, such as Sicomin's range of GreenPoxo resin systems. A significantly high percentage of the carbon content of these formulations is from plant and vegetable origins, as specified in ASTM D6866 standard.

'Our next generation bio-based epoxy systems represent a major step forward towards a petrochemical-free system derived from renewable resources,' said Philippe Marcovich, president of Sicomin.

'The ECOBOARD Project shows people all around the world that choosing a more

sustainable product doesn't mean sacrificing performance or quality,' said Brett Giddings from Sustainable Surf. 'The world's best stand-up paddle athletes, like Zane Schweitzer and Connor Baxter, are winning world titles on Starboard ECOBOARDS made with Sicomin bio-epoxies. Kiteboarding legend, Ruben Lenten, recently launched the world's first Gold Level kiteboard in partnership with Lieuwe and Sustainable Surf, proving ECOBOARDS also work in the air.'

Sicomin; www.sicomin.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.010>

Mold process improves aircraft production

Sicomin, which makes epoxy systems, and its South African composite materials distributor, Aerontec, have been working with The Airplane Factory (TAF) to help improve production methods for the company's range of Sling aircrafts.

The Sling is a lightweight aluminum and composite aircraft which can be purchased as a fully constructed and test flown aircraft or as a home build kit. Previously the composite undercarriage was wet laminated and then cut to shape, but the very thick glass epoxy laminate was difficult to laminate and trim and TAF required a more efficient and less labor intensive alternative.

The original wet lamination process was replaced through the development of a new net-shape, two-part infusion mold which allowed the undercarriage of the Sling 2 and Sling 4 aircraft to be infused



The Sling is a lightweight aluminum and composite aircraft.

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SR8100 is designed specifically for infusion and resin transfer molding (RTM) techniques and has secured Lloyd's



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SR8100 is designed specifically for infusion and resin transfer molding (RTM) techniques and has secured Lloyd's

Register and Germanischer Lloyd approvals. It is currently utilised by industrial, marine, energy, transportation, sports and leisure customers.

Sicomin's SR1126 fire retardant epoxy is used to make the composite components

of the certified version of the Sling 2 aircraft, the Sonaca S200. The canopy front arch, air vents, cowlings and the cockpit interior are all laminated with the aerospace, FST approved system. The Sling 2 parts are laminated in glass fiber molds

and post-cured at an elevated temperature following demolding.

Sicomin; www.sicomin.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.009>

Ultra-thin prepreg for watch

North Thin Ply Technology (NTPT), which makes ultra-lightweight prepreps, has supplied its materials for a limited-edition watch.

The prepreg material has been used to make the new RM 11-03 McLaren Automatic Flyback Chronograph jointly commissioned by Richard Mille and McLaren Automotive.

NTPT has developed new Thin Ply materials for Richard Mille since 2013 and says that its stiff and lightweight Carbon TPT composites can help improve the mechanical performance of the watches as well as being resistant to harsh environments. This project involved creating a new thin ply (52 g/m²) quartz prepreg with UV resistance, color homogeneity and non-allergenic material.



The prepreg material has been used to make the new RM 11-03 McLaren Automatic Flyback Chronograph.

The prepreg was made with Saint-Gobain's Quartzel quartz fibers and a custom Polylyte H hot melt resin from Polynt Reichhold.

NTPT;
www.thinplytechnology.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.008>

Lanxess supports racing team

Lanxess says that it has become a premium sponsor of, and has supplied materials to, a racing team from Cologne University in its bid to win Formula Student – a design competition which has more than 900 universities worldwide taking part.

'Autonomous driving, e-mobility, and new infrastructure concepts are changing the automotive landscape – and with it the plastics industry. By 2025, around 80% of all vehicles produced worldwide will have alternative drives,' said Jan Bender, head of marketing for EMEA in the Lanxess High Performance Materials (HPM) business unit. 'We develop high performance plastics for lightweight applications for every area of the automobile. In addition to body elements, plastics are replacing traditional steel structures in the chassis and drive system,' Bender explains.

According to Bender the principle is comparable to that of the human skeleton, whereby the fibers in the composite materials provide the necessary stability to the plastics under stress. This makes it possible to produce plastic components in areas where the material was previously consid-



Lanxess has supplied materials to a racing team from Cologne University.

ered unsuitable. Even highly stressed brake pedals can now be made from glass fiber-reinforced plastic, which can reduce the weight of the pedal by more than 40%, the company says.

Lanxess; www.lanxess.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.007>

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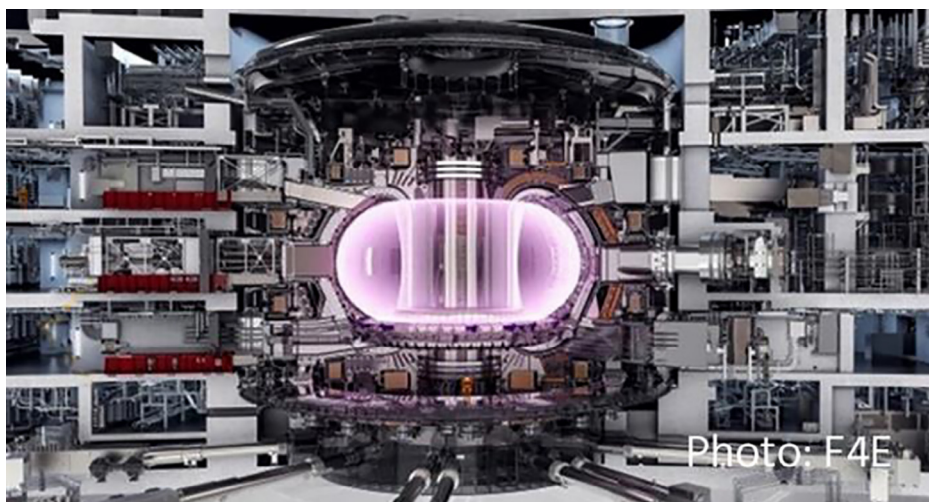
Composites for thermonuclear reactor

Pultrusion company Exel Composites is collaborating with French industrial contractor CNIM to make glass fiber components for the magnet support structure of the International Thermonuclear Experimental Reactor (ITER), the world's largest experimental fusion facility.

To fulfill the quality demands for the pre-compression rings, Exel Composites had to produce defect-free pultruded profiles of around 3 km in length.

The €18 billion ITER under construction in Saint-Paul-lez-Durance, France, has been designed to demonstrate that fusion power can be produced on a commercial scale, providing a safe, environmentally sustainable energy source. The ITER will use hydrogen fusion, controlled by superconducting magnets, to produce massive heat energy. In the commercial machines that will follow, this heat will drive turbines to produce electricity.

The composite pre-compression rings ensure the operation of the toroidal field coils that are employed to create a magnetic 'cage' to confine the 150 million °C plasma. To reduce fatigue and deformation of the coils resulting from the powerful magnetic fields, three pre-compression rings will be placed on top of them and three below, while an extra set of three will be manufactured in case replacement becomes necessary in future. The pre-compression rings are required to withstand maximum hoop stresses of up to 500 MPa at room temperature. Glass fiber epoxy composite with a high fiber content was selected as the most suitable material



The International Thermonuclear Experimental Reactor (ITER) is reportedly the world's largest experimental fusion facility.

to withstand such extreme loads, avoid circulation of electromagnetic currents and deliver a long service life. The composite rings will have a diameter of approximately 5 m, a cross-section of nearly 30 cm × 30 cm and will weigh slightly more than 3 tons.

The process uses on pultruded composite profiles produced by Exel Composites whereby each ring will be produced by winding a 2 mm thick, 2.8 km long, flat pultruded profile around a metal tool. A 0.12 mm thick epoxy adhesive tape is wound over each layer. The completed ring lay-up is cured and then machined to the required final dimensions.

Exel formulated an epoxy resin system to meet the mechanical specifications for

the pre-compression rings and ensured that the 3 km profiles supplied were defect-free along their entire length by means of online non-destructive testing (NDT). The handling of this length of profile presented a further challenge, which Exel solved by winding the product on a customized bobbin for supply to CNIM.

CNIM has already manufactured a series of prototypes, which are currently undergoing NDT and qualification tests. Production of the full-scale pre-compression rings will begin later this year.

Exel Composites;
www.exelcomposites.com

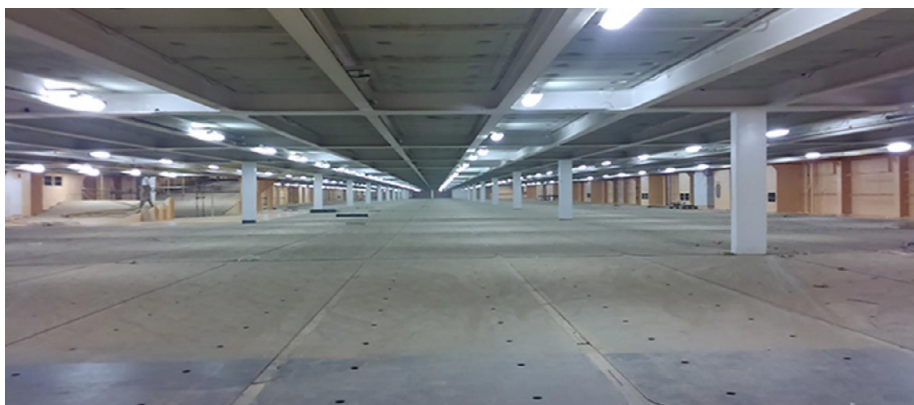
0034-3617/<https://doi.org/10.1016/j.repl.2018.06.006>

Composite core for car carrier vessel

Diab says that it has supplied a range of its Divinycell cores as part of Hungarian shipbuilder Uljanik JSC's SIEM Cicero project.

The project involved the building of a car carrier vessel designed for up to 7000 cars and features glass reinforced plastic composite structures for three of its cargo decks. According to Diab, the key benefits of the composite vessel include reduced fuel consumption, increased payload and reduced production lead time.

The project received a JEC Innovation Awards in 2018 for its innovative character and environmental impact.



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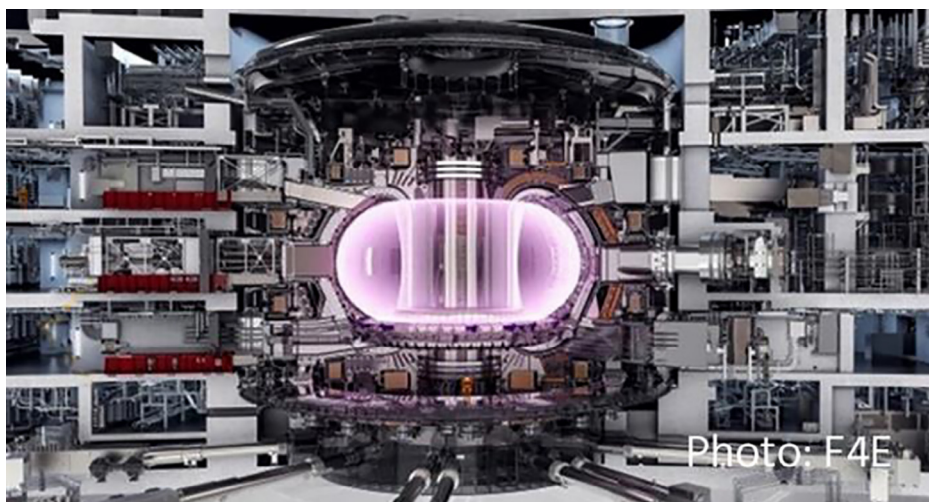
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'SIEM Cicero is the first extensive application of sandwich composite in the shipping industry, where each deck uses 770 m² of Divinycell H100 and 2570 m² of Divinycell H80,' said Roger

Jansson, group product and marketing manager at Diab. 'With the use of innovative materials and technologies, we are able to reduce the environmental impact while cutting cost.'

Diab; www.diabgroup.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.005>

Cobra International develops composite windsurfing board

Thai composite supplier Cobra International has formally launched the mass production of the new Windsurfer LT, a composite windsurfing board.

The board can be raced, used for teaching or freestyle and even paddled as a stand-up paddleboard on no wind days.

Prototypes of the board were built at Cobra's factory in Thailand and tested throughout 2017, with the team going through several design iterations before arriving at the current combination of board shape, rocker, underwater profile



The board can be raced, used for teaching or freestyle and even paddled as a stand-up paddleboard on no wind days.

and weight. The final board was created using a lightweight EPS core, glass combi fabrics and a bio based foaming epoxy using Cobra's advanced surf technology (AST) process. The board is reportedly 6.5 kg lighter than an equivalent design in traditional materials, and the company plans to evaluate a fully recycled EPS core option for the future.

Cobra International;
www.cobrainter.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.004>

New woven tape for marine applications

Composite reinforcement specialist Chomarat has developed a new unidirectional woven tape for its C-TAPE line of products, suitable for industrial production.

The new C-TAPE has been used to reinforce the foils of the Figaro Beneteau 3, reportedly the first ever production foiling one-design monohull made. The foils have been designed to improve the monohull's stability and performance. Fifty plies of tape were used to make the foil to help stress resistance and the specific structure of C-TAPE can help facilitate resin flow throughout the thickness, Chomarat says. The reinforcement provides the desired mechanical performance and also cuts down on production time.

According to Chomarat, C-TAPE offers a lot of flexibility in terms of weight, width and construction. The weft yarn makes the tape easy to handle and to work with and it is produced in 50 cm widths in order to adapt better to the mold, helping reduce scrap and production cost.

'The project was an ambitious one,' said Multiplast general manager Yann Penforis. 'We had to reach a lower target cost,



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By the end of summer 2018, around one hundred foils will have been produced

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Chomarat; www.chomarat.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.003>

Innovative fire safety cabinet

A University of Bristol engineering student has helped a UK business win its second Queen's Award in five years.

The Queen's Awards for Enterprise are the UK's most prestigious business awards to celebrate and encourage business excel-

lence, and five years ago fire safety equipment company Jo Bird received its first Queen's Award for International Trade.

'SIEM Cicero is the first extensive application of sandwich composite in the shipping industry, where each deck uses 770 m² of Divinycell H100 and 2570 m² of Divinycell H80,' said Roger

Jansson, group product and marketing manager at Diab. 'With the use of innovative materials and technologies, we are able to reduce the environmental impact while cutting cost.'

Diab; www.diabgroup.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.005>

Cobra International develops composite windsurfing board

Thai composite supplier Cobra International has formally launched the mass production of the new Windsurfer LT, a composite windsurfing board.

The board can be raced, used for teaching or freestyle and even paddled as a stand-up paddleboard on no wind days.

Prototypes of the board were built at Cobra's factory in Thailand and tested throughout 2017, with the team going through several design iterations before arriving at the current combination of board shape, rocker, underwater profile



The board can be raced, used for teaching or freestyle and even paddled as a stand-up paddleboard on no wind days.

and weight. The final board was created using a lightweight EPS core, glass combi fabrics and a bio based foaming epoxy using Cobra's advanced surf technology (AST) process. The board is reportedly 6.5 kg lighter than an equivalent design in traditional materials, and the company plans to evaluate a fully recycled EPS core option for the future.

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'The biggest difficulty we had was with production,' said Guy Atkins, managing director of Jo Bird. 'When we started running the process, there were high occurrences of defects and scraps. I enrolled on a mentoring scheme run by the National Composites Centre (NCC) to improve my composites knowledge. We decided to sponsor a University of Bristol Engineering Doctorate (EngD) student to overcome the production issues and to transfer knowledge to the company's staff.'

As a result of this sponsorship, graduate engineer Laxman Sivanathan joined the team at Jo Bird and implemented changes to reduce the direct costs in the manufac-



Engineering student Laxman Sivanathan who has been sponsored by Jo Bird. (Photo courtesy Jo Bird.)

ture of the cabinets, as well as integrating product innovations.

'It is great to see that the practical implementation of my academic research at Jo Bird has contributed towards winning this prestigious award in Innovation,' said Sivanathan. 'I could not have done without the continuous support from Dr. Carwyn Ward at the University of Bristol,

Guy Atkins from Jo Bird and my faith, which have been the driving force behind this achievement. I would also like to acknowledge EPSRC for supporting this research.'

Jo Bird; www.jobird.co.uk

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.002>

FRP bridges require reduced maintenance

Composite Advantage has developed a new line of standard size fiber reinforced polymer (FRP) trail bridges that have a zero maintenance option that reportedly lasts up to 100 years.

Based on the supplier's FiberSPAN-T trail bridge first installed in 2008, the standard FRP system comprises a prefabricated FRP composite deck with weathered steel beams and powder-coated aluminum railings to resist salt, water and chemical corrosion.

The bridges are available in sizes 20–50 ft and meet American Association of State Highway and Transportation Officials (AASHTO) guide specifications for pedestrian bridge designs. They have a non-slip surface which supports safe foot traffic and lasts five to six times longer than traditional sand-in-paint finishes, the company says. It is available in colors that include brown, green and gray. The bridges arrive on-site fully assembled so installation can take just one day.



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'Our new standard line of prefabricated bridges makes selection easier for customers, shortens lead times, and reduces costs with production efficiencies,' said Scott Reeve, president of Composite Advantage.

Composite Advantage;
www.compositeadvantage.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.001>



Business

Financials

Our roundup of composites-related financial reports over the last two months.

Gurit reported an increase in net sales for the first three months of the year of 5.4% compared to the same period of 2017.

Gurit Composite Materials achieved net sales of CHF 62.9 million for the first quarter of 2018, a decrease of 6.8% compared to net sales of CHF 67.4 million for the first three months of 2017. According to the company, this decline results from the continued low material demand level in the wind energy industries in India and China. Sales to other material markets, mainly marine and industrial, rose by 6% compared to Q1 2017 and amounted to CHF 33.2 million for the first three months of 2018.

Gurit Composite Components revenues declined slightly reportedly due to temporarily lower build rates in one of the existing programs and the time gap until the start of volume production of new projects. Net sales amounted to CHF 4.5 million for the first quarter of 2018 versus CHF 4.8 million in the first quarter of 2017.

However, Gurit Tooling's net sales increasing by 62.9% to CHF 24.7 million in Q1-2018 compared to net sales of CHF 15.2 million in the first quarter of 2017. 'The strong performance results from the continued high demand for new and larger wind blade molds for the production of increasingly efficient wind turbines,' Gurit said in a press release.

Hexcel Corporation says that it has had an increase of 12.8% in Q1 sales to US\$540.1 million. Commercial Aerospace sales of US\$382.7 million increased



A key driver of SGL's operational sales increase was the improved performance of SGL's automotive market segment.

10.2% (9.4% in constant currency) for Q1 of 2018 as compared to the prior year period while Space & Defense sales increased 17.5% (13.6% in constant currency) to of US\$90.1 million.

Total Industrial sales of US\$67.3 million for Q1 of 2018 increased 22.6% (10.3% in constant currency) when compared to Q1 of 2017, and wind energy sales (the largest sub-market in Industrial) improved 10.6%.

'2018 is off to a solid start, with Hexcel generating record sales with growth across all of our markets, as well as increasing adjusted diluted earnings per share by over 13% year-over-year,' said Nick Stanage, CEO. We also generated positive free cash flow during the quarter – the first time in

recent history we have done so in the first three months of the year, further underscoring Hexcel's transition to a cash generation cycle.

SGL has published group sales of €263 million, up by about 22% from €216.3 million in the previous year, due to positive one-time effects and a good operational development, the company said.

Key drivers of the operational sales increase were reportedly the improved performance of SGL's automotive, semiconductors and LED, chemicals as well as industrial applications market segments.

The company's composites segment increased its sales revenues by 22.9% (currency adjusted by 26%), to reach €115.0

million, up from €93.6 million, while sales in the textile fibers and wind segments declined compared to prior year level. The highest earnings improvement was recorded in automotive, primarily resulting from the full consolidation of SGL Composites (previously SGL ACF).

As a result, SGL Group says that it now expects a consolidated net result in the lower double-digit million euro range for full year 2018 and says sales will increase by approximately 10%. This includes a sales

increase of approximately 25% primarily as a result of acquisitions for composites, while sales with the automotive industry should more than double. At the same time sales with the wind industry could decrease by about one third, owing to the deconsolidation of a former joint venture as well as the weaker customer demand. SGL says that sales should slightly increase in aerospace, while sales in industrial applications and textile fibers should remain around the level of the previous year.

'Following the good financial year 2017, we are continuing our positive development this year,' said Dr. Jürgen Köhler, CEO. 'The new SGL remains on a growth track.'

Gurit; www.gurit.com
Hexcel Corporation;
www.hexcel.com
SGL; www.sglgroup.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.034>

Bid for lightweight composite powertrain parts

Thermoset companies Vyncolit NV and Sumitomo Bakelite Co Ltd say there is a pressing need for lightweight parts in both internal combustion and electric motor-based drivetrains.

The subject was discussed during the Lightweight Composite Solutions Conference which reportedly took place in Ghent, Belgium in April 2018.

The switch to Vyncolit NV and Sumitomo Bakelite Co Ltd. plastics and materials in parts such as fuel pumps, electric motor housing and brake system parts could dramatically reduce weights and costs, the companies say.

'Powertrains, be they conventional, hybrid or fully electric, will need to be light in weight if carmakers are to meet the stringent regulations on carbon dioxide emissions (CO₂) to come into force in 2025 – and composites will be key to making this happen,' a press release said.

In Europe, the fleet average emissions to be achieved by all new cars in 2021 is 95 g of CO₂ per km. By 2025, this could be reduced further to 75 g of CO₂ per km. The average emissions level of a new car sold in 2016 was 118.1 g of CO₂ per km.

'All OEMs, have a lot of work to do in the next six to seven years,' said MD of Vyncolit NV, Pieter Vanderstraeten.



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Sumitomo Bakelite Co Ltd;
www.sumibe.co.jp/english

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.033>

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Lockheed Martin Rotors and Mission Systems (Sikorsky) has awarded Hexcel's Salt Lake City, USA facility a prize for its product quality and delivery performance.

This award for performance in 2017 was presented to nine companies. Hexcel was selected for this award by leadership at Sikorsky.

Hexcel supplies carbon fiber, matrix, core and dynamic components including main rotorcraft blades, blade spars, skins, skins-to-cores, tip caps, tip skins, cuff spacers, and flex beams for Sikorsky rotorcraft platforms.

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Hexcel; www.hexcel.com

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As a result, SGL Group says that it now expects a consolidated net result in the lower double-digit million euro range for full year 2018 and says sales will increase by approximately 10%. This includes a sales

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Hexcel; www.hexcel.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.032>

Quickstep CFO to leave business

Quickstep Holdings, an Australian manufacturer of carbon fiber composites, says that its chief financial officer (CFO), Andrew Crane, will depart from the business to spend more time with his young family. The company has begun a formal search and selection process for his replacement and Crane will be available

to support the new CFO through a handover period.

'It is highly regrettable that Andrew has decided to stand-down from his role as CFO. He is a highly valued member of the executive team and has seen the company through an important period of transition, a change of CEO, the implementation of

OneQuickstep and our strong move toward sustained profitability and positive cash-flow,' said Mark Burgess, CEO of Quickstep.

Quickstep Holdings;
www.quickstep.com.au

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.031>

RTP company expands operations in Europe

RTP Company, which makes custom engineered thermoplastics, has expanded its presence in Poland by building a 7990 m² facility in Wroclaw. The plant will support regional demand and provide a supply of the company's custom compounded thermoplastics to customers in Europe.

The facility is expected to open in summer of 2018, and is anticipated to employ 25 or more people. It will feature a wide dock area and a high clearance ceiling and will accommodate up to six production lines, RTP says.

'RTP Company is excited to expand service to our customers in the European

market through the addition of this facility in Poland,' said Danny Miles, RTP Company's vice president and managing director – Europe.

RTP Company;
www.rtpcompany.com

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Arburg UK celebrates 25th anniversary

Arburg Ltd base in Warwick, UK reportedly celebrates its 25th anniversary in 2018. The UK subsidiary began with an 18-strong team headed up by Frank Davis. Since 2005, Colin Tirel has been MD of the subsidiary, and today the Arburg team has a total of 26 employees, 17 of whom work in after-sales.

The main focus is on the production of thermoplastic parts, but in recent years, the areas of liquid silicone rubber (LSR) processing and multi-component injection molding have grown, Arburg says. One of the trends in the UK and Ireland is towards larger, multi-cavity molds and Arburg is reportedly well positioned to cope with this, due to the extension of the clamping force range up to 6500 kN.

Arburg; www.arburg.com

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From right to left Eugen and Juliane Hehl, managing partners, Stephan Doepler, European director sales, Colin Tirel, MD, Gerhard Böhm, managing director sales, and Frank Davis, former subsidiary manager.

4M Carbon Fiber Corp appoints new CEO

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the company's president and will also be on the corporation's board of directors.

'Rob's expertise, knowledge, and network in the carbon fiber industry is exactly what 4M needs at this stage to ensure the company maximizes the value of the technology,' said Kimmel.

For the past 10 years, Klawonn was president of Teijin Carbon America (formerly Toho Tenax America) and since 2015, he has also been president of Diversified Structural Composites, a Teijin subsidiary producing various pultruded components for the wind energy and

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'Our goal is to stand up multiple carbon fiber production lines in the next five years,' said Rodney Grubb, chairman and chief operating officer of 4M. 'With his extensive background and industry experience, Rob will be instrumental in helping us to do that.'

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Owens Corning's annual sustainability report

Owens Corning has published its 2017 Sustainability Report documenting the progress made against its 2020 sustainability goals and its stated commitment to making the world a better place.

From the 2010 baseline year, Owens Corning reportedly exceeded goals for primary energy (–26%), water (–41%), and fine particulate (–25%) and is on track to meet goals for greenhouse gas (–48% to date) and toxic air emissions (–61% to date). However, it continues to be challenged by its waste-to-landfill goal (–4% to date), the report said.

The company also purchased over 1.1 million megawatt hours of renewable energy.

With regards to product and supply chain sustainability, the company developed what it says is the world's first products certified as made with 100% wind-powered electricity and reduced embodied carbon, including various EcoTouch and Thermafiber insulation products.

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DSM to increase global Dyneema production capacity

Royal DSM says that it plans to increase production capacity for its Dyneema strong fiber due to market demand for both Dyneema uni-directional laminate (UD) and Dyneema fiber.

The company will install additional new UD technology at its plant in Heerlen, the Netherlands, and its plant in Greenville, North Carolina, US and will also make improvements to existing production lines to expand capacity. The global production capacity of

Dyneema UD will be increased by more than 20%.

DSM Dyneema also plans to improve its carbon footprint. DSM's Greenville plant already uses 100% renewable electricity.

Dyneema UD is a composite unidirectional laminate that offers improved energy absorption and protection. It is available as a hard and soft ballistic material.

'DSM Dyneema is the world's largest UHMwPE fiber and UD manufacturer

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Growth for continuous fiber

The continuous fiber composites market could grow at a CAGR of 5.5% and 6.3% between 2017 and 2022 to reach US \$2,506.5 million, according to a new report.

Research and Markets says that some of the factors driving the market are stringent

governmental regulations, improvement properties compared to conventional materials, and growing demand from various end-user industries.

Research and Markets;

www.researchandmarkets.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.024>

Growth in automotive carbon fiber components market

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According to the report, one driver influencing this market is the growing use of carbon fiber materials in the automotive industry. The automotive industry is focusing on the use of energy-efficient, rigid, and light-weight materials to reduce adverse environmental effects and grow-

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The procurement of energy and water within the competitive market has become

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Companies should provide consultants, Briar Associates with a recent bill who will then look at cost saving opportunities from improved procurement and tariff infrastructure changes and identify-

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AM partnership focuses on aerospace

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The companies aim to employ AM technology to make cabin parts. The goal of the partnership is to accelerate the use of AM equipment in the aviation sector with

a focus on these parts for new aircraft, as well as for the retrofit market.

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BigRep; bigrep.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.018>

Funding for UK composite projects

The Engineering and Physical Sciences Research Council (EPSRC) Future Composites Manufacturing Research Hub has announced the funding of two new feasibility studies, following a call for proposals issued in October 2017.

Each award of £50,000 will fund a six-month research project in composites manufacturing. Proposals were invited from UK academia for projects that addressed research in recycling and waste-reduction, and microwave processing.

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If Ashland decides to sell these assets, it would expect to sign an agreement by the end of 2018, the company concluded.

Ashland; www.ashland.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.020>

Composites UK offers energy procurement service

Composites UK says that it now offers an energy and water procurement service to its members.

This service is in addition to its climate change levy discount scheme (CCL) which was put in place in 2017, allowing users of carbon fiber to claim back CCL on their energy bills.

The procurement of energy and water within the competitive market has become

a great deal more complex over recent years and requires an understanding of tariff structures, market movements and which are the most competitive suppliers at any time, the organization says.

Companies should provide consultants, Briar Associates with a recent bill who will then look at cost saving opportunities from improved procurement and tariff infrastructure changes and identify-

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For more information, go here: www.compositesuk.co.uk/utilities

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AM partnership focuses on aerospace

BigRep, which makes thermoplastic filaments for 3D printing, and Etihad Airways plan to jointly develop new plastic additive manufacturing (AM) products for the aerospace industry.

The companies aim to employ AM technology to make cabin parts. The goal of the partnership is to accelerate the use of AM equipment in the aviation sector with

a focus on these parts for new aircraft, as well as for the retrofit market.

According to the two companies, there is a need for a wider spectrum of AM-suitable polymer materials that can pass the aerospace certification process. At present, one of the main factors prohibiting a breakthrough of AM for aircraft cabin interiors is the absence of a broader variety of

high-performance materials that are EASA and FAA-certified. Both parties have agreed to jointly develop and test new material grades in accordance with EASA and FAA criteria.

BigRep; bigrep.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.018>

Funding for UK composite projects

The Engineering and Physical Sciences Research Council (EPSRC) Future Composites Manufacturing Research Hub has announced the funding of two new feasibility studies, following a call for proposals issued in October 2017.

Each award of £50,000 will fund a six-month research project in composites manufacturing. Proposals were invited from UK academia for projects that addressed research in recycling and waste-reduction, and microwave processing.

The call received 16 proposals from 12 academic institutions across the UK and the titles of the studies chosen for funding are:

Microwave (MW) heating through embedded slotted coaxial cables for composites manufacturing (M-Cable), Dr. Mihalis Kazilas, Brunel University.



The EPSRC Future Composites Manufacturing Research Hub is a £10.3 million investment to expand UK research in the production of polymer matrix composites.

Acceleration of monomer transfer molding using microwaves, Professor Derek Irvine, University of Nottingham.

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Cimcorp; cimcomp.ac.uk

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.017>

Victrex predicts boost in thermoplastic composites

Victrex says that thermoplastic composites will be developed over the next few years

to meet demand for over 35,000 new aircraft required within the next 20 years.

According to Victrex, thermoplastic composites offer multiple advantages,

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Hexcel and Arkema join forces

Hexcel and Arkema have signed a strategic alliance to develop thermoplastic composites for the aerospace sector.

The partnership aims to develop carbon fiber-reinforced thermoplastic tapes to produce lightweight parts for aircraft. The aim is for the new composites to provide lower cost and faster production speeds

for aerospace and the space and defense sectors.

As part of this partnership, a joint research and development laboratory, located in France, will be established.

'This association fits in clearly with our strategy to develop advanced thermoplastic composite solutions from our PEKK

resins, and takes effect a few months before the commissioning of our new PEKK plant in the United States in Mobile (Alabama) scheduled for the end of 2018,' said Thierry Le Hénaff, Arkema CEO.

Hexcel; www.hexcel.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.011>



Technology

Low viscosity epoxy for medical electronic applications

Master Bond has developed a biocompatible two part epoxy with a mixed viscosity of 150–300 cps that has been formulated for medical electronic applications. Master Bond EP62-1LPSPMed has ultra low viscosity which makes it suitable for use in underfill, impregnation and porosity sealing applications, as well as bonding, coating or encapsulation, the company said. This product exhibits improved wetting properties and can flow by capillary action in tight clearances or beneath devices. It adheres well to metals, plastics, compos-

ites, polyimides, glass and ceramic substrates.

EP62-1LPSPMed has a working life of 12–24 h for a 100 g mass and requires moderate heat for curing. Cure schedule is overnight at room temperature followed by 60–90 min at 80–100 °C.

Master Bond EP62-1LPSPMed passes USP Class VI and ISO 10993-5 cytotoxicity requirements. It also has been tested for 1000 h at 85 °C/85% RH. It has improved toughness, tensile strength of 11,000–12,000 psi and resists repeated cycles of

ethylene oxide, radiation, and chemical sterilization. This compound has volume resistivity of more than 1014 ohm-cm, withstands mechanical shock/vibration and is serviceable from 4 K to +400 °F. In very thin sections it will transmit light, but in thicker sections it is opaque. Shore D hardness is 75–85 and its glass transition temperature is 125–130 °C.

Master Bond;
www.masterbond.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.050>

Lower cost prepregs now available

Total Composite Solutions (TCS) says that it now offers a range of prepregs, with a high TG available in standard reinforcement weights of 245 g and 600 g bulk ply. Other heavier weights are available along with a lower cost option, the company says.

‘We are delighted to launch this new Tooling Service and offer our customers full onsite technical support along with this extensive choice of prepregs,’ said Andrew Pointon, managing director.

Total Composites Solutions;
www.totalcompositesolutions.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.049>

Composite bonding for aerospace

Solvay has developed FusePly, a composite bonding technology for aerospace applications.

According to the company it can help build bonded composite parts using conventional manufacturing processes, through the creation of covalently bonded structures, potentially removing the need for abundant rivets and fasteners.

FusePly reportedly offers clear step-change bonding performance along with improved reliability. When compared to mechanical fasteners, the adhesive can offer higher performance since drilling holes into fiber-reinforced structures can introduce structural damage and create stress concentrations that could reduce the load capacity of the part. The reduc-

tion and replacement of fasteners with FusePly bonding could also reduce the overall weight of the aircraft. Adhesives offer much greater design flexibility during manufacture and assembly at lower cost, says Solvay.

Solvay; www.solvay.com

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Pultrusion conference report published

The European Pultrusion Technology Association (EPTA) has published an in-depth report on its 2018 conference,

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The 12-page document, World Pultrusion Conference 2018: Attractive Long-Term Prospects for Pultruded Composites,



Technology

Low viscosity epoxy for medical electronic applications

Master Bond has developed a biocompatible two part epoxy with a mixed viscosity of 150–300 cps that has been formulated for medical electronic applications. Master Bond EP62-1LPSPMed has ultra low viscosity which makes it suitable for use in underfill, impregnation and porosity sealing applications, as well as bonding, coating or encapsulation, the company said. This product exhibits improved wetting properties and can flow by capillary action in tight clearances or beneath devices. It adheres well to metals, plastics, compos-

ites, polyimides, glass and ceramic substrates.

EP62-1LPSPMed has a working life of 12–24 h for a 100 g mass and requires moderate heat for curing. Cure schedule is overnight at room temperature followed by 60–90 min at 80–100 °C.

Master Bond EP62-1LPSPMed passes USP Class VI and ISO 10993-5 cytotoxicity requirements. It also has been tested for 1000 h at 85 °C/85% RH. It has improved toughness, tensile strength of 11,000–12,000 psi and resists repeated cycles of

ethylene oxide, radiation, and chemical sterilization. This compound has volume resistivity of more than 1014 ohm-cm, withstands mechanical shock/vibration and is serviceable from 4 K to +400 °F. In very thin sections it will transmit light, but in thicker sections it is opaque. Shore D hardness is 75–85 and its glass transition temperature is 125–130 °C.

Master Bond;
www.masterbond.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.050>

Lower cost prepregs now available

Total Composite Solutions (TCS) says that it now offers a range of prepregs, with a high TG available in standard reinforcement weights of 245 g and 600 g bulk ply. Other heavier weights are available along with a lower cost option, the company says.

‘We are delighted to launch this new Tooling Service and offer our customers full onsite technical support along with this extensive choice of prepregs,’ said Andrew Pointon, managing director.

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is available to download from the EPTA website and covers the global trends such as sustainability which continue to drive the adoption of composite materials in numerous industries including construction, transportation, consumer goods, and the electrical and chemical sectors.

According to the report, pultrusion, one of the few continuous processes for manufacture of composite parts, enables the cost effective, high volume production of structural profiles and the market for pultruded composites has been experiencing steady growth.

The report addresses the following topics:

- growth drivers for the pultrusion industry
- promising application areas for pultruded composites in infrastructure, building and construction, wind turbine blades, automotive components and other sectors
- advances in materials designed to improve performance and productivity, including the latest developments in polyurethane resins and epoxy pultrusion systems and new anhydride curing agents
- research initiatives focused on novel reinforcements, microwave-assisted pultrusion and in-line non-destructive testing (NDT)
- progress in standardization in the US and Europe.



Infrastructure is a key growth market for pultruded composites.

EPTA's World Pultrusion Conference is a biennial event and the largest forum for the pultrusion industry in Europe. The next conference will take place in 2020.

The European Pultrusion Technology Association;
www.pultruders.org

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.047>

New lighter weight structural compounds

RTP Company, which makes custom engineered thermoplastics, has developed new thermoplastic compounds that reportedly weigh 5–10% less than typical filled compounds, and have equivalent mechanical properties and similar shrinkage values.

According to the company representatives, the compounds can make parts molded with glass fiber reinforcement lighter without compromising performance or requiring modifications to existing tools.

In tests compared to standard glass fiber reinforced materials, there can be a dramatic difference in density and a slight difference in tensile strength, RTP says. Unlike chemical foaming agents, the density reduction is not dependent on wall thickness and since the compound can be used as a drop-in solution with existing tooling, the switch from other materials can be a smooth transition.

'LT Compounds from RTP Company are best used as lightweight alternatives when the goal is to minimize energy consumption or the amount of human effort



This handheld, battery-operated tool is one of many possible applications for RTP's compounds.

required to use the part, said Jason Kafader, structural product manager at RTP. 'This makes them an ideal material for handheld, battery-operated tools, sporting goods, handheld appliances, recreational vehicles, and other common markets for

glass fiber reinforced compounds that will benefit from reductions in weight.'

RTP Company;
www.rtpcompany.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.046>

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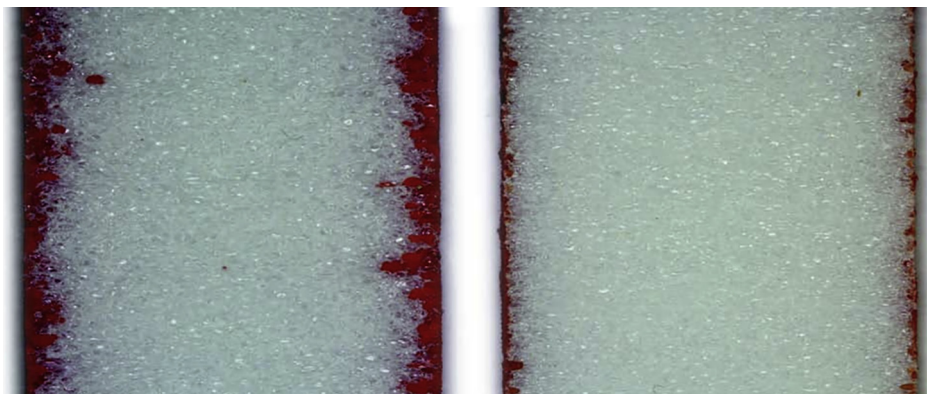
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Foam core could reduce resin infusion cost

3A Composites Core Materials says that the resin uptake analysis on a 6500 kg hybrid core wind blade showed that its AIREX T92.100 SealX core significantly reduced cost and time when compared to standard PET foam core.

The analysis was conducted in a real production of the hybrid core blade, where 3A's material and standard PET foam core were compared in shear web and shell infusion. The blade total core was 151 m² and weighed 342 kg, while the shear web was 100% PET core, and the shells hybrid.

Using AIREX T92.100 SealX the total resin saving was more than 3%, equivalent to 57 kg less weight in comparison with the standard PET core, according to 3A. The material was applied in 57 m² and saved 1 kg/m² with a core weight reduction of 29% and a coating surface savings



Infused PET standard PET foam 100 kg (left) versus AIREX T92 SealX (right).

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3A Composites Core Materials;
www.airexbaltekbanova.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.045>

CF tape for oil and gas markets

Solvay has introduced Evolite F1050, a polyvinylidene fluoride (PVDF) continuous carbon fiber composite tape suitable for oil and gas applications.

Evolite F1050 is a unidirectional tape with the chemical and temperature resis-

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Evolite F1050 has mechanical and chemical resistance and is suitable for high temperature applications. It is compatible with automated tape laying (ATL) pro-

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Solvay; www.solvay.com

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Solvay expands coatings additives portfolio

Solvay has introduced a new line of products for binder, color and performance systems. The new products reportedly deliver improved emulsion stability, particle-size control, adhesion to difficult substrates, pigment wetting and dispersion, color acceptance, compatibility and workability. They have high scrub, stain and water resistance and offer open-time or freeze-thaw improvement for the development of environmentally friendly formulations intended for architectural paints, industrial coatings, adhesives and printing inks.

Binder products include Rhodasurf, Rhodafac, Rhodapex and Aerosol surfactant solutions, as well as the Sipomer PAM, WAM and B CEA series of APE and

VOC-free specialty adhesion monomers which can improve adhesion to metals such as aluminum, cold rolled steel and other difficult substrates.

Color products include Rhodoline 3000 and 4000 dispersants for water-based pigment concentrates which help provide improved color intensity, color acceptance improvement, high stability and viscosity, facilitating the development of formulations intended for different applications in architectural paints, industrial coatings and printing inks. Rhodoline WA 265N is a new VOC and APE-free, low-foaming wetting and dispersing agent designed for waterborne architectural paints for improved pigment wetting,

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Solvay; www.solvay.com

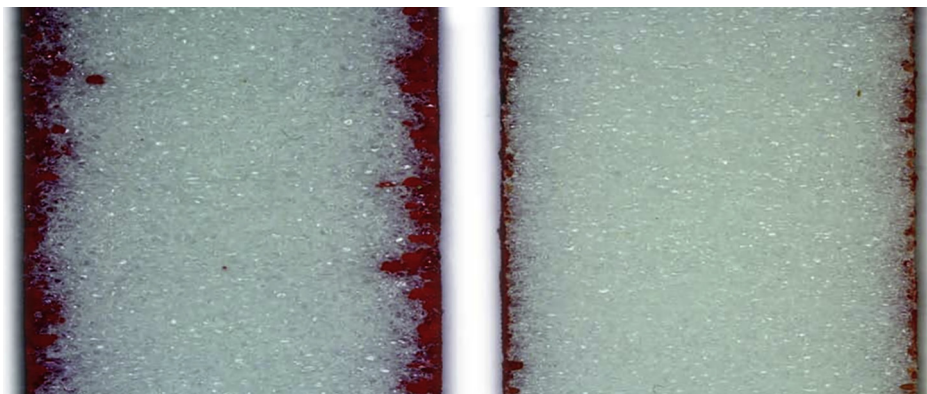
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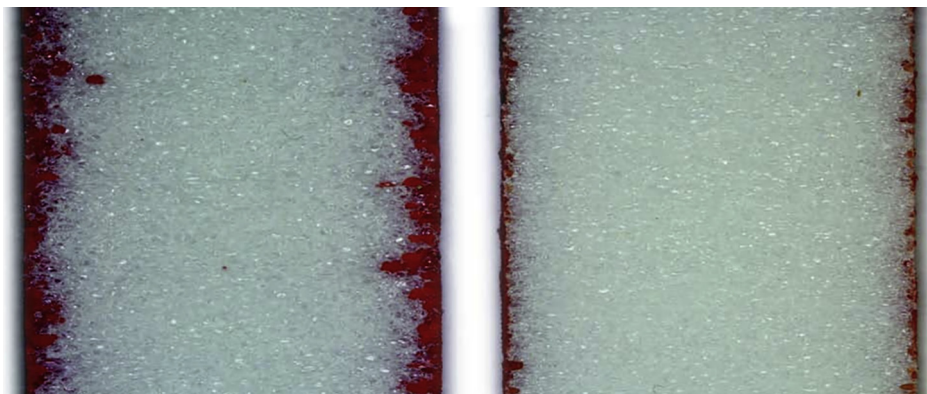
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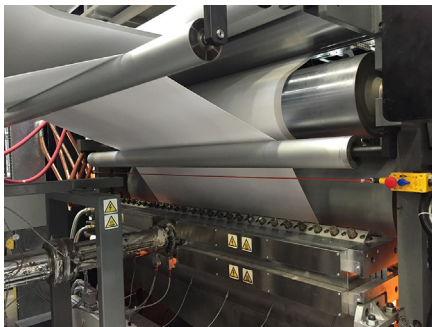
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AMUT provides membrane line

Italian plastics company AMUT has provided a new geomembrane line to Jingmen Keshun. Jingmen Keshun New Material, a Chinese distributor of coatings and membranes.

The line produces waterproofing membranes in thermoplastic olefin TPO which can reach an output of 2.200 kg/h, (around 7 million m²) annually. The maximum width is 2.000 mm and the line can deliver three layer reinforced membrane with a single calender system with inner



The line produces waterproofing membranes in thermoplastic olefin (TPO).

reinforcement in glass fiber or polyester scrim. It is also possible to insert a non-woven reinforcement for the lower layer of the membrane.

AMUT; www.amutgroup.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.042>

Direct coating improves piano black appearance

Hyundai America Technical Center and coating specialist Covestro LLC have joined forces to explore a new processing technique called direct coating to make high-gloss piano black for interior and exterior automotive trim components.

Direct Coating technology combines conventional thermoplastic injection molding with reaction injection molding (RIM) to deliver a hard polycarbonate blend substrate with an ultraviolet-stabilized, scratch and chemical-resistant polyurethane coating with a piano black finish.



Direct coating technology could eliminate the need for painting and results in a durable finish.

polyurethane coating raw materials which were tailored to improve adhesion between the two material formulations while also meeting the chemical and mechanical performance requirements of the finished part.

Covestro LLC; www.plastics.covestro.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.041>

Recent prototypes have used a Covestro PC + ABS blend material and aliphatic

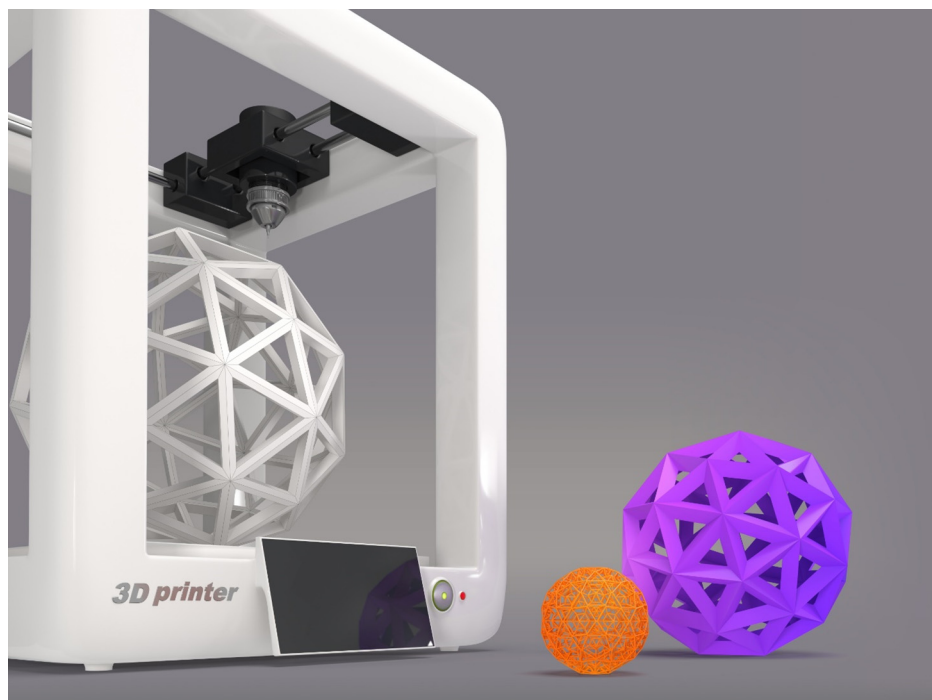
Nanodiamonds boost 3D printed polymer performance

Finnish nanodiamond manufacturer Carbodeon and Dutch 3D printing specialist Tiamet 3D have announced the first nanodiamond-enhanced filaments for 3D printing.

The Carbodeon/Tiamet 3D filaments are based on a jointly-patented technology which can help improve the mechanical and thermal properties of 3D printed items.

'By joining forces we've already developed filaments with a 100% increase in tensile strength, improved printability, and better thermal properties,' said Reid Larson, CEO of Tiamet 3D.

'Nanodiamonds offer the potential to make 3D-printed components that perform as well as or better than comparable injection molded components, but with massive cost reductions and production speed improvements, especially for prototype, on-demand and short run production,' added Carbodeon CEO Dr Vesa Myllymäki.

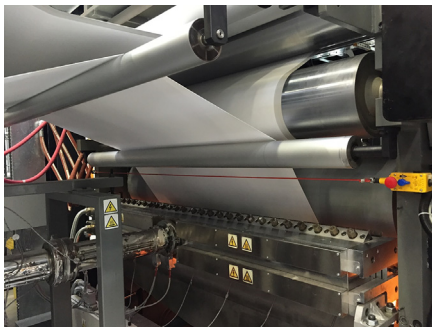


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The line produces waterproofing membranes in thermoplastic olefin TPO which can reach an output of 2.200 kg/h, (around 7 million m²) annually. The maximum width is 2.000 mm and the line can deliver three layer reinforced membrane with a single calender system with inner



The line produces waterproofing membranes in thermoplastic olefin (TPO).

reinforcement in glass fiber or polyester scrim. It is also possible to insert a non-woven reinforcement for the lower layer of the membrane.

AMUT; www.amutgroup.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.042>

Direct coating improves piano black appearance

Hyundai America Technical Center and coating specialist Covestro LLC have joined forces to explore a new processing technique called direct coating to make high-gloss piano black for interior and exterior automotive trim components.

Direct Coating technology combines conventional thermoplastic injection molding with reaction injection molding (RIM) to deliver a hard polycarbonate blend substrate with an ultraviolet-stabilized, scratch and chemical-resistant polyurethane coating with a piano black finish.



Direct coating technology could eliminate the need for painting and results in a durable finish.

polyurethane coating raw materials which were tailored to improve adhesion between the two material formulations while also meeting the chemical and mechanical performance requirements of the finished part.

Covestro LLC; www.plastics.covestro.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.041>

Recent prototypes have used a Covestro PC + ABS blend material and aliphatic

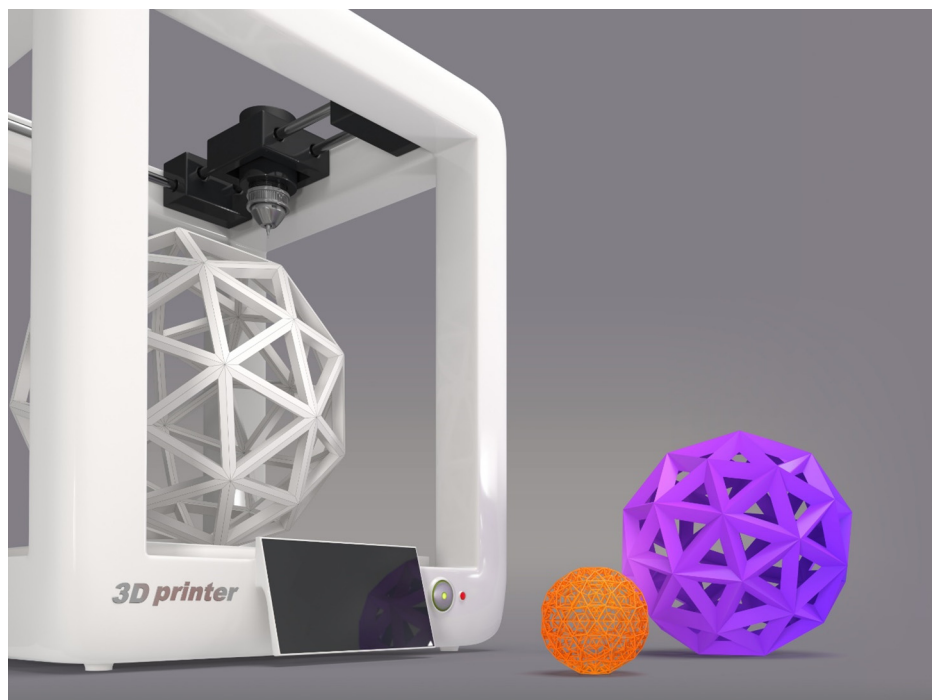
Nanodiamonds boost 3D printed polymer performance

Finnish nanodiamond manufacturer Carbodeon and Dutch 3D printing specialist Tiamet 3D have announced the first nanodiamond-enhanced filaments for 3D printing.

The Carbodeon/Tiamet 3D filaments are based on a jointly-patented technology which can help improve the mechanical and thermal properties of 3D printed items.

'By joining forces we've already developed filaments with a 100% increase in tensile strength, improved printability, and better thermal properties,' said Reid Larson, CEO of Tiamet 3D.

'Nanodiamonds offer the potential to make 3D-printed components that perform as well as or better than comparable injection molded components, but with massive cost reductions and production speed improvements, especially for prototype, on-demand and short run production,' added Carbodeon CEO Dr Vesa Myllymäki.

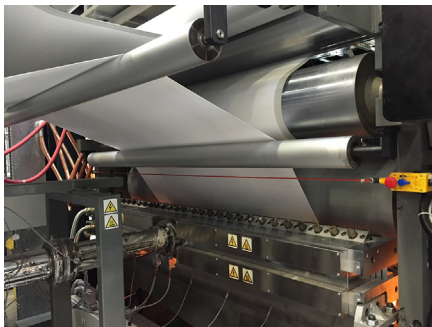


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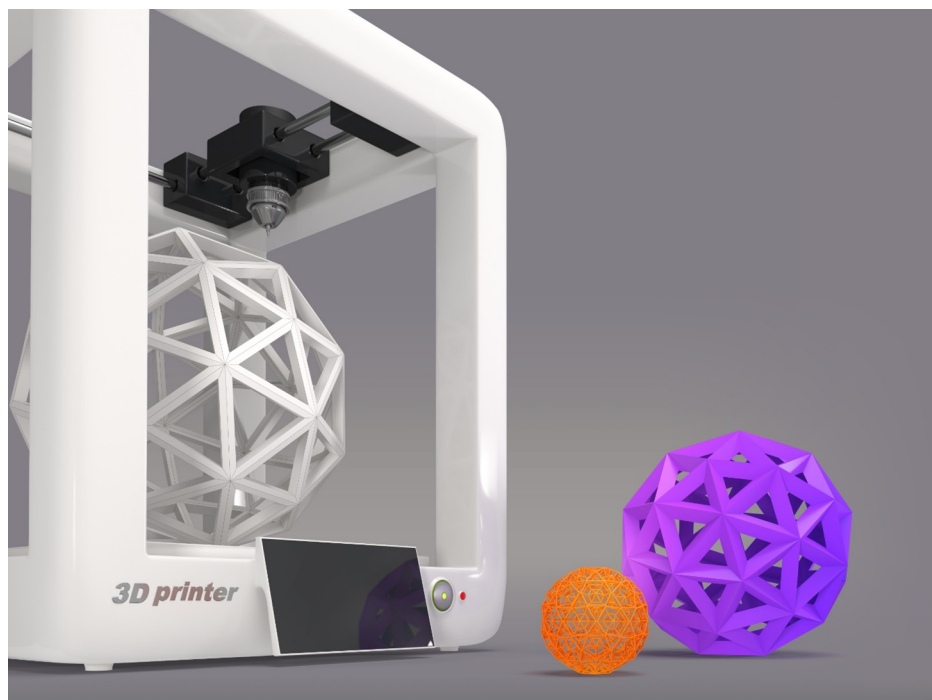
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The technology could help improve the mechanical and thermal properties of 3D printed items.

3D printing using these thermoplastics could be suitable for the electronics, automotive and aerospace industries. Nanodiamonds can increase the glass transition temperature of the end product

or component making them suitable for challenging environments, the companies say.

The first Carbodeon/Tiamet 3D filaments will be PLA (polylactic acid) based,

with further development focused on other thermoplastics.

Carbodeon; www.carbodeon.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.040>

Solvay announces winners of 3D printing prize

Solvay has announced the winners of its Additive Manufacturing Cup. Launched last October, the competition invited university students to 3D print complex polymer shapes using the company's KetaSpire polyetheretherketone (PEEK) filament.

Submissions were evaluated for mechanical stability and aesthetic qualities by a panel specialising in polymer technology, design and additive manufacturing. The winners received first, second and third prizes of €10,000, €5000 and €3000.

Winning first place was the ePEEK team from Arts et Métiers ParisTech, France,

which 3D printed PEEK parts that exhibited an exceptional tensile strength of 80 MPa in the z-axis, a performance similar to injection molding.

In second place, the Jugao team from Xi'an Jiaotong University, China won a prize for 3D printing a Solvay logo using the filament.

In third place, the Chloé Devillard team from Claude Bernard University Lyon 1, France demonstrated creativity and innovation in resolving the technical challenges of printing tensile specimen in the z-axis without any support material.

'The winners exemplified the AM Cup challenge by pushing the capabilities of additive manufacturing to produce a 3D-printed PEEK part with a tensile strength rivaling that of an injection molded part,' said Stéphane Jéol, president of the jury and technology manager for Solvay's global specialty polymers business unit.

Solvay; www.solvay.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.039>

SencorpWhite introduces thermoforming machine

SencorpWhite has announced the release of the Ultra 2 thermoforming machine. According to the company, the machine is equipped with a more robust, heavy-duty, rail transport system which makes it possible to use less material and produce less waste.

The Ultra 2 uses a proprietary off-load system, which is up to 70% faster than previous designs, says SencorpWhite. It includes inline steel rule tools to help reduce tool and labor costs and shorten production time.

SencorpWhite;
www.sencorpwhite.com

0034-3617/<https://doi.org/10.1016/j.repl.2018.06.038>

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Changing the paradigm of transportation: Lightweight composites used in solar car in intercollegiate competition

Elizabeth Howell, Dylan Neal, Dakota Kieffer

Reinforced Plastics spoke to Dylan Neal, the Project Director of Team PrISUm Solar Car from Iowa State University, and Dakota Kieffer, Director of Sales and Marketing, Plastics Unlimited, about the PrISUm solar car project.

I understand that Plastics Unlimited has been working with Iowa State University PrISUm solar vehicle team for the past few months, could you explain more about the project?

Dylan: PrISUm at Iowa State University is constructing the world's first fully, consumer oriented solar electric vehicle. The team of 120 members ranging from engineers, designers, education, and business are dedicated to changing the ideal of transportation. In the current automotive industry, there is a shift to sustainable and electric solutions. The vehicle will be a four door, practical vehicle that never has to hit the plug in but maintains the efficiency of your standard plug in EV (Fig. 1).

Dakota: Plastics Unlimited has been helping out the PrISUm team by cutting foam patterns that will be used to make fiberglass tools. We have also worked on changing the designs so we could cut the patterns and then verify that the molds and parts would be able to release. We had to make sure there were no die locks or parts of the patterns that would be difficult to produce reliable end products. We are able to use our large CNC's to cut patterns up to 10 feet wide by 12 feet long. Cutting very large patterns helped the PrISUm team assemble the SUV in fewer pieces (Fig. 2).

Plastics Unlimited has also been helping the PrISUm team by Thermoforming parts for them. We have been working with the Iowa State University students to teach them about the thermoforming process including why molds have to have draft, what happens when the tools get too warm, the importance of getting a good seal so the vacuum can form the plastic, and many other tips and tricks.

What is PrISUm's main focus?

Dylan: The main focus of the program is to shift the paradigm of transportation. However, to continue innovation, there needs to be people ready to face the challenge. The program strives to

not only innovate and perform advanced material, integrated system, and automotive research, but teach and inspire younger generations through outreach.

What new materials and technologies are currently entering the sector and what do you foresee on the horizon?

Dylan: We foresee composites, carbon fiber and lightweight plastics, taking over the industry. As research furthers and manufacturing methods become cheaper, the average vehicle begins to incorporate more advanced materials. For example, Ford vehicles have moved to Aluminum chassis. Other vehicles from a range of manufacturers are using lightweight composite for paneling and structure. PrISUm's four door incorporates all of the aforementioned materials and aims to bridge the gap between fiction and reality.

Dakota: We believe materials that are light weight and strong will continue to replace steel in the automotive sector. Composites including carbon fiber and fiberglass are a great fit in the high performance automotive sector currently. High performance cars like the Ford GT, Corvette, Koenigsegg, McLaren, Ferrari, Lamborghini, and many others are using an increasing percentage of composites all of the time. Once composites can be manufactured quicker and more cost competitive, I think we will see them used and may more vehicles and other products as well. We see advanced honeycomb and other highly engineered lightweight materials continuing to be used more often (Fig. 3).

How are fiberglass tools and carbon fiber parts being developed to meet market needs?

Dylan: The idea with fiberglass tooling is to do more with less. Carbon tools are incredibly expensive yet allow for high toler-

**FIGURE 1**

Dylan Neal, Team PrISUm Solar Car Project Director.

ance parts to be pulled. Fiberglass and open molding is much less time intensive, cheaper, and more commonly used in other applications. As a solar car program, and a development group, we are constricted to find creative methods to still achieve good, accurate parts. As we have utilized fiberglass tooling for our various panels and body of the vehicle, we have found that it is feasible to make carbon parts from fiberglass tooling that fit the design criterion.

Dakota: Fiberglass tools can be much cheaper option compared to cast aluminum or machined aluminum tooling. This can make the tools cost competitive for low volume production. The carbon fiber parts can be produced in a way so all of the

**FIGURE 2**

Dakota Kieffer, Director of Sales and Marketing of Plastics Unlimited.

fibers in the carbon fiber are positioned or oriented for optimal performance and extremely light weight. The designs in carbon fiber are not limited as much as most other materials so designs and engineers have more potential. As more designers and engineers continue to learn about the design characteristics and possibilities of carbon fiber, the more potential advanced composites will have. One of the largest factors that limit composites and

**FIGURE 3**

The PrISUm Solar Car and its team members.

plastics is that not as many designers and engineers feel comfortable using them. They learn more and have much more experience with metals and other material that have been around for a much longer time.

What are the major challenges facing the sector?

Dylan: Cost and time. In any fiberglass or carbon composite material, the cost always becomes a factor. Then, coupled with cost, is the idea that composites take varying cure times with sometimes varied results. We at PrISUm are excited to see how the market and technology adapts to these constraints so composites can be swapped out for more commercial, established products.

Dakota: The composites market is aware that they have to make the processes quicker and more cost competitive if they want to get into high volume and cost sensitive markets like the automotive market. They have been working on it for years. One way that carbon fiber can be cheaper is out-of-autoclave parts. Plastics Unlimited is currently working on more cost sensitive out-of-autoclave carbon fiber parts for the aerospace market. The raw materials are cheaper for out-of-autoclave carbon fiber compared to pre-impregnated carbon fiber. The out-of-autoclave carbon fiber is also faster to produce because there is no need to put it in an oven for hours under vacuum.

Carbon fiber has of course been invaluable in making products lighter, but what are some of the other key advantages in vehicle manufacturing?

Dylan: The key advantage to carbon structure is geometry. With carbon fiber, you are limited to the geometry capacities of your tool. Incredibly diverse and lightweight structures can be created with the use of carbon fiber – which in turn can be modified to benefit many more aspects such as aerodynamics and vehicle dynamic performance.

How can PrISUm's project help to develop the automotive sector?

Dylan: As a research and applications initiative program we look to push the realm of what is possible, yet provide a stepping stone from the present to the future. Through our program, we are setting the bar so the automotive industry, and many other industries, can use composite technology and electric technology to surpass the methods of today. We set the bar through proving inexpensive methods of manufacturing, what technologies to use, the ever-growing availability of composites and pioneering the way. In a sense, we look to perform the upfront R&D for automakers.

What's the next step for PrISUm?

Dylan: Moving from a single seat vehicle to our multi passenger, consumer oriented design, the next step is to improve. Our program has learned a great deal and broken down the walls of limitations. There were many bumps in the manufacturing process of our vehicle. Now, after we educate the community and make a presence through the World Solar Challenge in the international and national community, the design of the next car will be refined. We look to perform more in depth cost analysis, smarter design, more integrated design, and design a vehicle that will further prove the reality that EV's and electrical design will be the new norm.

How do you think that the research community, industry, manufacturers, and government best work together to enable new developments?

Dylan: It is my belief that the best way for industries to work together is through projects like ours. The vehicle is a statement to the possibilities of every technology we use. The purpose of the vehicle is to make a statement and raise questions of "how can we do that?". Additionally, the key to following forward is with education. If all new, thriving industries can educate one



FIGURE 4

The PrISUm Solar Car revealed to the public for the first time.

another, no one will start from nothing and progress can be made (Fig. 4).

In your opinion, what are the other hot topics in fiberglass, and indeed other materials, right now?

Dylan: Carbon structure and its development is growing rapidly. As there is a new standard for electric vehicles and renewable solutions, lightweight and efficient design can be created through clever composite structure, plastics and carbon fiber. Another rapidly growing entity, that we use on our program, is the concept of additive manufacturing. In the consumer market, there is a greater desire for customization. As the market

as grown for AM, and cheaper technology, we can see clever design and fully integrated solutions.

Dakota: Some of the worst parts of fiberglass are how the gelcoat cracks and how long it has to be in the molds. Both of those problems are solved using Plastics Unlimited's TEC Process (Tooless Engineered Products) which bonds a thermoformed ABS plastic surface layer to a structural layer of fiberglass. This forms an extremely strong, durable product that does not chip or crack like gelcoat. The thermoformed part is utilized as the fiberglass tool. This allows us to produce fiberglass parts much faster. We can also form any textures or prints including wood grain or carbon fiber printed plastic.

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Bigger, stronger, faster... pushing the envelope of 3D printers to turn them into true production tools

Django Mathijsen

The 3D printer has already matured into a useful and versatile tool for making models, mock-ups and prototypes. But researchers, engineers and designers are working hard to eliminate the limitations of 3D-printing and take the next step. The goal is to take the machine out of the lab and into the factory, from rapid prototyping to additive manufacturing. Reinforced Plastics talks to people on this new frontier, pushing out the boundaries of 3D printing.

The 3D printer has proven its value in turning designs into actual objects without needing a craftsman. All you need is a CAD-system and a good engineer who can turn your ideas into printable designs.

However, objects printed by 3D printers are mostly still limited to models, prototypes and toys due to the limitations of 3D-printing technology. Depending on the type of 3D printer, only relatively small, low-strength and low-resolution objects can be printed. The range of materials and material mixes that can be printed, is limited. And the process should be faster and cheaper for it to be viable in a factory environment, making end-user products in a way that can compete or coexist with traditional manufacturing techniques.

One of the companies, working on the frontier of 3D printing, expanding its applications, is "3D robot printing" (<https://www.3d-robotprinting.com/> See Figure 1).

Printing larger objects

About four years ago Jasper Menger, the founder of 3D robot printing, converted a 2-meter long robot arm into a 3D printer (Figure 2). He joined the SuGu Warehouse, a building in the Rotterdam (Netherlands) port area, housing entrepreneurs working on innovative, sustainable production techniques. The company has since doubled its revenues every year.

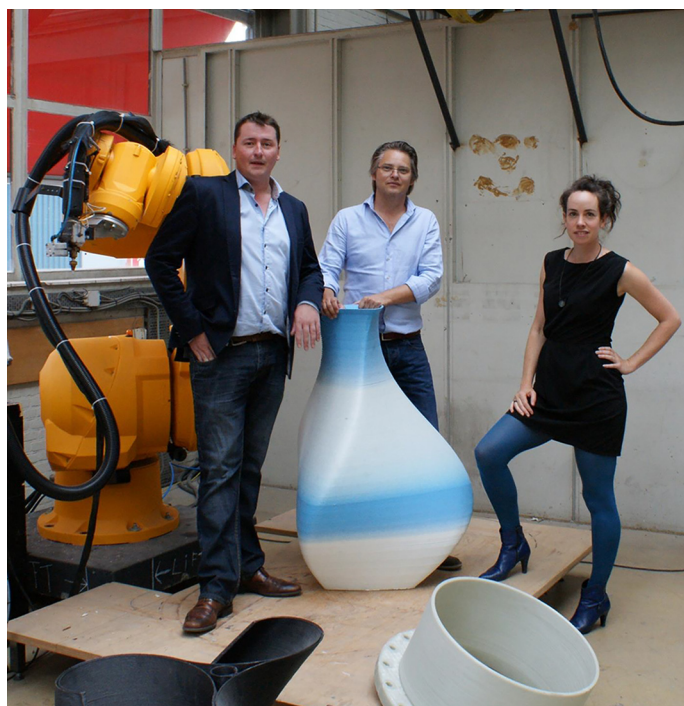
Menger used to work as a mechanic for Rolan Robotics. "He was actually trying to build a plastics welding robot for industrial purposes," Eliza Noordhoek says, who is responsible for design and production at 3D robot printing. "But that gave him so many problems that he was near giving up. Back then, the welding torch was not far enough developed yet. Then he realized

that the machine he had built, almost was a giant 3D printer. So, he converted it to exactly that."

The 3D robot printer is basically an extruder mated to an industrial robot. It is not fed with filaments, but with granulates. And the material of choice at the moment is glass fiber filled polypropylene (Figure 3).

"That material has little shrinkage, is very strong, delivers repeatable results, and can be processed and finished very well," Noordhoek explains. "We cannot print all types of composite materials. That is mainly due to their melting temperatures. After the extruder, the material flows through a three-meter-long, heated hose that runs along the robot arm. So, the material has to flow for quite a long way before it arrives at the print nozzle. Some fibers will scorch traveling that long path. Or the material will degrade."

Natural fibers tend to get scorched if the material is at the temperature where the matrix will flow. But Noordhoek has noticed an increased demand for products made of bio-based materials. So, they are testing wood fiber reinforced plastics, trying to make them work for the 3D robot printer. And they have already successfully printed objects in polylactic acid (PLA) filled with bamboo fibers (Figure 4). "That is a rather difficult material," Noordhoek says, "especially because we print large objects, which means that all the side-effects of extruding thermoplastics layer by layer – like shrinkage and tearing – become bigger as well. So, it is more of a problem for us than for a desktop 3D printer. We have seen some tearing using bamboo fiber filled PLA. But it depends on the material batch: with a good batch, there are no problems. With a bad batch, it does not work at all." The reason for that is subject to further research.

**FIGURE 1**

The team of “3D robot printing” with their 3D printing robot “Susan”. From left to right: Jasper Menger, René Ritmeijer and Eliza Noordhoek. In the foreground three of the many objects it has already printed in glass fiber reinforced polypropylene: a vase, a boat propeller, and a flange for off shore pipes (contracted by IHC Holland.) (Photo courtesy of 3D robot printing).

When you scale up 3D printing of plastic objects, the problems with temperature differences, stresses and tearing are bigger not only because the product is larger, so stresses can build up over larger load paths, but also because the temperature differences in the product as it is printed tend to get larger.

“In small printers, you can cheat a little to get around problems,” Noordhoek says. “With large printed objects, you really have to look at the problem and solve it. And I think we have higher expectations for our products than most objects that come out of a desktop 3D printer. If we print a chair, it must really be strong enough to take the weight of a person sitting on it. And we print a lot of industrial objects, which have to adhere to stringent specifications.” (Figure 5).

Rubber can also be printed. And Noordhoek expects printing carbon fiber filled polypropylene to be possible as well, but they have not had an assignment for that yet: “For printing transparent objects we use styrene acrylonitrile, but that is quite brittle. Polypropylene is our ideal printing material, but that is also because we have a lot of experience with it.”

Noordhoek says that requests for printing objects are coming in from all industries now: “Maritime, automotive, aerospace... and we are getting requests from architects to 3D print larger structures. A tiny house and a pavilion for example.”

From the outset, the 3D robot printer was intended to make actual usable products that go beyond prototypes and can take structural loads and prolonged use. The 3D robot printing company has already been hired to make a lot of objects, varying from a submarine (Figure 6) to a recumbent bike (Figure 7).

**FIGURE 2**

Robot Susan printing an object. The machine is basically an extruder mated to an industrial robot arm (Photo courtesy of 3D robot printing).

“We developed a wind tunnel for the Delft University of Technology,” Noordhoek says (Figure 8). “That was a huge step forward for us, because it was much larger and heavier than anything we had made up to then. It had to be within very tight measurement tolerances. And it needed to be super smooth in order to not cause any turbulences.”

Plastics welding robot

In the meantime, they have also got the plastics welding robot to work (Figure 9). So, by combining the two robots, the size of the objects that can be made is virtually unlimited now. “We are currently working on a 16 meters tall object with a base of about 4 by 4 meters,” Noordhoek says. “We divide that into segments and weld them together. And then we coat it or add a finish. We can clean off all the seams left by the welding process and out comes one object.”

The plastics welding robot uses a filament instead of granulate. “It has for example been implemented in the production line of Vink Kunststoffen (www.vinkkunststoffen.nl) for the production of pool trays,” Noordhoek says. “Those are large rectangular boxes, made up of sheets of plastic. They do not vary a lot in measurements. The welds are straight but very long and that

**FIGURE 3**

Jasper Menger represented the city of Rotterdam at the World Expo in Milan in 2015, with his 3D robot printer and this 3D printed chair. It takes about four hours to print the chair.

**FIGURE 4**

Although glass fiber filled polypropylene is currently the material of choice, the machine can also print bio-based materials. This chair for example was printed in bamboo filled PLA (Photo courtesy of 3D robot printing).

makes them difficult for a human to make at consistent quality. A robot will make those welds faster and at higher quality."

Next to making objects for customers to order, 3D robot printing also develops and sells their robot technology. And they

**FIGURE 5**

This 3D printed boat propeller is more than half a meter in size and has to be within stringent tolerances (Photo courtesy of 3D robot printing).

**FIGURE 6**

This six-meter-long hull was printed to be assembled as the prototype for a two-seater submarine for underwater maintenance work. It was designed and commissioned by Filip Jonker, the CEO of Ortega Submersibles (Photo courtesy of 3D robot printing).

design custom production installations for customers. "We are also developing a milling robot," Noordhoek adds, "based on a 5-axle machine, to see if it can finish our objects fast." If they can realize the milling robot as well, imagine the future possibilities of setting up a fully automated 24/7 3D printing production line with three stages of industrial robots. The first stage prints the segments. The second stage welds them together to form rough products. And the final stage finishes them. No humans required... except of course for the engineers who do the maintenance and develop the software and the designs.

Many car manufacturers now have websites where you can put together your own car on-line: you can choose things like engine size, options, colors, wheels, etcetera. Can the customer in the future design his own variation on a basic bumper, hood

**FIGURE 7**

(a) and (b) The frame of this recumbent bike, powered by a cordless drill, was 3D printed for students of the Fontys School in Venlo (The Netherlands), who used it in a race. The whole frame and seat is one 3D print, which takes the robot about 14 h to make (Photo courtesy of 3D robot printing).

or dashboard – for example adding his own bulges, scoops, vents and spoilers – and have it 3D printed by a robot? “We are working with a builder of luxury yachts to 3D print some very creative parts,” Noordhoek answers. “So, the technology is suitable for non-structural parts on ships and cars to enable personalization and mass customization.” And maybe even car seat frames can be 3D printed based on a 3D scan of someone’s backside. They have already made a copy of a statue, using a 3D scan (Figure 10) (see Fig. 11).

The devil is in the software

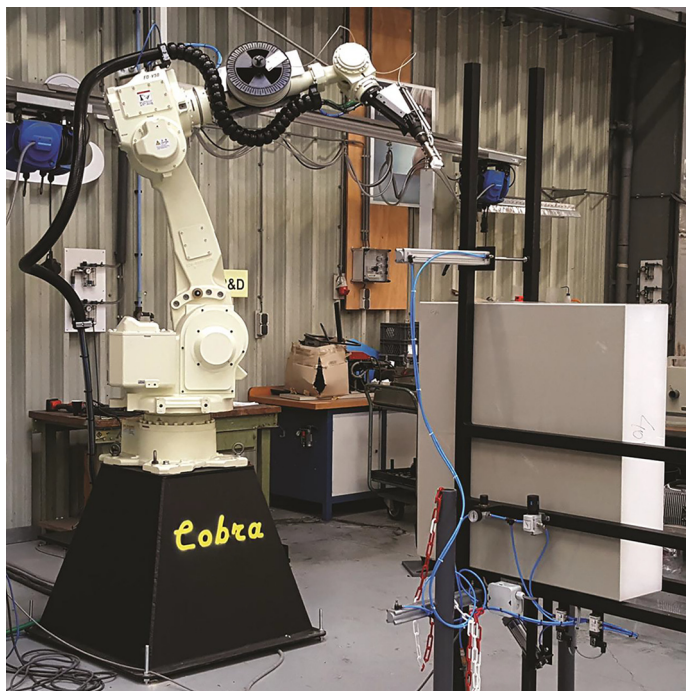
In the world of 3D-printing, software is king, as Noordhoek explains: “The most complicated part of the printing as well as the welding robot is the software. We are constantly developing

**FIGURE 8**

(a) and (b) This 6 by 3-meter large 3D printed wind tunnel was made for the Delft University of Technology (Photo courtesy of 3D robot printing).

that to take away limitations. A lot of the problems adapting the process to different materials for example can be solved with software. We do not have to adapt the hardware that much. We constantly keep learning what the optimal parameter values are for different materials and products to realize a good print. The devil is really in the software details.”

In a factory with all robots, human brains are needed instead of human hands: Noordhoek stresses that in such a factory, product design and engineering will be more important and extensive. Because doing the pre-engineering and programming the 3D printer can be straightforward for some objects. But for more

**FIGURE 9**

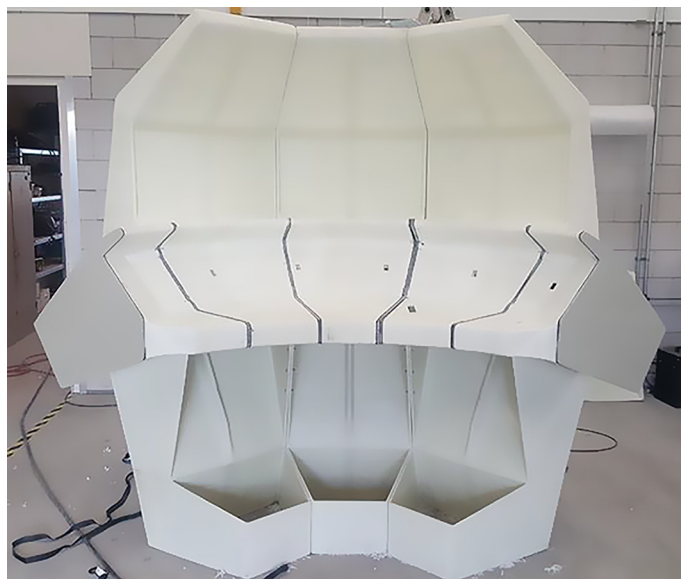
A plastics welding robot has also been developed (Photo courtesy of 3D robot printing).

**FIGURE 11**

The original statue of Erasmus was scanned. "Making that scan was quite difficult," Eliza Noordhoek of 3D robot printing says. "It is a unique statue, because it is the oldest bronze statue in the public space in the Netherlands" (Photo courtesy of 3D robot printing).

**FIGURE 10**

This statue is a 3D printed replica of a statue from 1622. It was made as a message connecting modern Rotterdam with its history. Maybe this technology can also help replace statues and monuments, lost due to disasters, wars, vandalism or terrorism (Photo courtesy of 3D robot printing).

**FIGURE 12**

This frame was printed for a train simulator (Photo courtesy of 3D robot printing).

complicated objects, it can take weeks. One of the main problems is making a design that is printable. You cannot just print a hollow cube in one step for example. Because then the lines you try

to print at the top, would just fall in. You should always build objects from the bottom up (Figures 12 and 13).

Overhangs can be printed, but you have to respect a maximum angle to the vertical, depending on material, thickness and cooling speed. Otherwise the material will sag or drip down. But on the other hand: many of these shape restrictions can be solved with clever engineering. You can for example print

**FIGURE 13**

(a) and (b) The train simulator in action (Photo courtesy of 3D robot printing).

support material that you can remove after the object has cooled down.

"We basically use two kinds of software," Noordhoek says. "One to divide the 3D design into layers. And the other to configure the robot. At the moment, we are using off-the-shelf software to divide the object into layers. We would like to develop our own in the future, because we have more requirements than possibilities with the existing software. We would like to have more control of what the robot is doing, that means: having more parameters to play with."

So, software is the most important area for further improvement. 3D robot printing wants to expand the range of materials they can work with. And they want to be able to print different materials at the same time.

**FIGURE 14**

Brandon Sweeney proving the strength of a chain link, printed with carbon nanotubes coated polylactide using his new 3D printing technology (Photo courtesy of Brandon Sweeney).

"We are also trying to define what this new way of manufacturing digital designs entails and what it is going to mean for the industry," Noordhoek says. "Our technology creates a lot of new possibilities. Where exactly is it going to fit in?"

Printing stronger objects

Where 3D robot printing is enabling 3D printing for manufacturing very large objects, Brandon Sweeney (26) is set to earn his PhD from Texas A&M University in a few months for enabling 3D printing for manufacturing objects where high strength is required, for example in medical, aerospace and automotive applications.

One of the fundamental problems holding back fused deposition modeling (FDM) or extrusion based 3D printing, where thermoplastic filaments are used to make the part, is that the resulting products are not as strong as parts made with injection molding. "The core technology is basically a hot glue gun where you are laying down successive layers of material," Sweeney explains. "The objective is to get those layers to bond together. But the fundamental thermodynamics that hamper that process

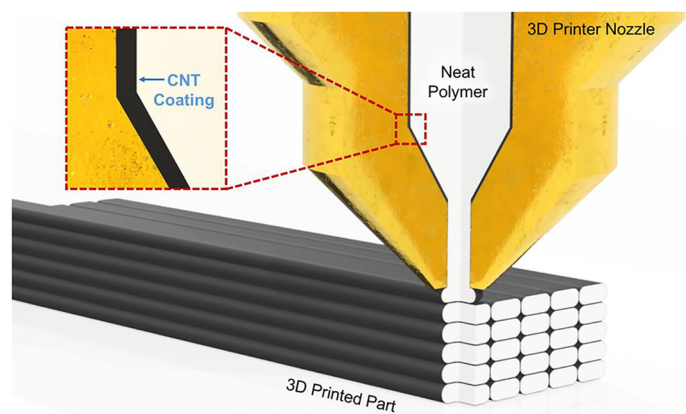


FIGURE 15

The carbon nanotubes (CNT) coating stays separate from the base polymer as the material is extruded through the 3D printer nozzle (Picture courtesy of Brandon Sweeney).

are that you need the part to be cool enough so it is not going to change shape or warp, and yet you want it to be hot enough for long enough in order for the layers to fully bond together to create a polymer weld. That is an engineering problem, because the hotter the material the stronger the bond, but the more likely you are to have dimensional changes and lose the shape you worked so hard to create."

Interlayer strength is the problem

So, the interlayer strength of 3D printed parts is a weak spot. Sweeney explains that putting a 3D printed part into an oven or autoclave after printing does not work: "We have tried that. But at the temperature where you get interlayer bonding, the shape of the object will change dimension and warp. That is the catch 22 with 3D printed parts. I did a lot of work for the army research labs as an undergraduate and have a strong background in polymers and manufacturing technology. So, I was very aware of this problem of interlayer bonding. I knew the general solution should be to thermally weld the layers together."

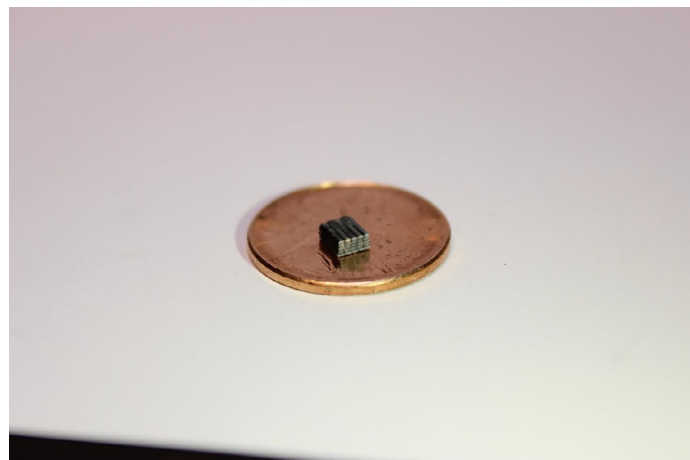


FIGURE 16

A piece of 3D printed material shows the scale at which the welding is performed (Photo courtesy of Brandon Sweeney).

Normal welding of plastic parts or metal frames is possible because of a thermodynamic trick: the material is heated up to beyond its melting point, but only in a localized area which is an order of magnitude or more smaller than the material dimensions you are bonding together. That way a strong bond can be created without appreciably changing the dimensional or structural properties of the product.

But heating up a 3D printed part only locally at all the layer interfaces seemed impossible to Sweeney: "How do you get a heating element down at the nanoscale to target each of those layers?"

Carbon nanotubes offer the solution

Sweeney explains that he got the idea for the solution, when he started his PhD: "My advisor, Dr. Micah Green, had done work targeting carbon nanotubes with microwaves in order to detect their presence. I thought: here are basically little resistive heating elements, far smaller than the dimensions we are trying to heat up. Could we take these materials and apply them to the layer interfaces of the 3D printed parts?"

So, they took some polymer pellets, spray painted them with carbon nanotubes and put them into a microwave. "In that first try, the power was far too high: it erupted into a little volcano," Sweeney says laughing. "Needless to say, it did weld together. Then we started to back off on the power and control things like the thickness of the layer we added. As we started to fine-tune it, we learned more about the physics and refined the process."

They made custom polymer filaments, thinly coated with carbon nanotubes, 3D printed objects with them and used microwaves to apply electric energy to the carbon nanotubes, locally heating up the interfaces between the layers. This bonds all the layers together, making the part about as strong as an injection molded part (Figure 14). "Each layer is on the order of a couple hundred microns: a very thin strand of plastic," Sweeney explains. "But if the layers we extrude with the 3D printer are 200 microns, the coating on the outside of the polymer is just a few microns thick. If we target that with electromagnetic energy, the base polymer itself is essentially transparent to the microwaves. Only the thin, active layer is generating heat. So now you have this embedded localized source of heat that can carry out a traditional welding process and you are not overheating the part to the point where you are destroying its structural integrity."

Welding at the nanoscale

When experimentation with carbon nanotube coated filaments was started, it was uncertain if the coating would mix with the polymer during the extrusion process in the 3D printer. That would have rendered the method useless. But as Sweeney explains, the coating turned out to stay a distinct, separate layer (Figure 15): "That is because the polymer is highly viscous. You have a very laminar, even, extensional flow. So, you are just thinning out the layers in the filament, not mixing them. It is like toothpaste with different colors or extruded drinking straws with stripes."

The carbon nanotubes act solely as resistive heating elements: they are not joining carbon nanotubes to carbon nan-

otubes. It is the polymer that is heated up to a temperature where it interdiffuses into itself. So, the process is comparable to welding plastic parts by putting a metal wire mesh between them and passing a current through it to bond the parts together. Except, now the heating elements and the welds are shrunk down to the nanoscale (Figure 16). As a bonus, the carbon nanotubes help improve the stiffness and mechanical properties.

So, this technology might be suitable for other plastic welding purposes as well. Sweeney gives an example: "I could imagine joining pipes together for petroleum or gas applications where you just paint on carbon nanotubes like a primer, use a connecting flange to put them together, apply electromagnetic energy and create a very strong weld in a matter of seconds." (If you are interested in the fundamental research and development of these technologies for other applications, please contact charles.b.sweeney@tamu.edu or micah.green@tamu.edu. For 3D printing specific areas, contact brandon@essentiummaterials.com).

Sweeney is also working on a project exploring the possibility of using carbon nanotubes in epoxies, urethanes and silicones as embedded heating elements to cure or crosslink the matrix rapidly and uniformly. But his main focus is on 3D printing and making the carbon nanotubes strengthening trick commercially available.

TriFusion

Sweeney and a fellow student at Texas A&M University founded TriFusion devices to apply his high-strength 3D printing technology in a field where it can impact people's lives in a positive way: printing customized orthotic and prosthetic devices that go out to partner clinics to be used on patients. "It fixes a problem that 3D-printing could not have addressed before," says Sweeney. They have already printed more than 350 devices. The carbon nanotubes do not pose a health risk to the patients, as Sweeney explains: "The prevalent consensus among the FDA and the general manufacturing community in the US is that as long as the carbon nanotubes are embedded in the plastic matrix and cannot be inhaled, they are safe. There are quite a few applications where these materials are out in the marketplace right now, with no evidence showing any long-term hazards."

TriFusion devices is now a fully owned subsidiary of Essentium Materials, which has licensed the core technology and is further developing it, trying to get it into the market place. That means: making customized polymer filaments of many engineering-grade polymers coated with carbon nanotubes, and integrating the technology into 3D printers.

OEM add-on kit

"We do not change the extrusion method at all," Sweeney says. "The filaments are standard 1.75 or 3 mm. You could use them with any desktop printer off the shelf. But to have the layers welded together, an additional applicator is needed to run electromagnetic energy into the 3D printed part as it is being printed. That is an accessory add-on we are currently aggregating with several partner printer companies. The goal is to have an OEM add-on kit that will result in a much higher interlayer bond strength than previously achievable."

In the experiments to prove the technology, microwaves were used to apply the electromagnetic energy. But a microwave source is rather expensive and must be contained inside a Faraday cage. So, in order to make the technology suitable for a commercial product, it was refined by replacing microwaves with radio frequency electromagnetic energy to generate the high current densities required in the carbon nanotubes of 3D printed parts.

"The core physics are the same," Sweeney explains. "But the applicator design we now have, actually uses a plasma as part of the conduction pathway to deliver energy into our parts. You can think of plasma as highly conductive nebulous clouds. The nice thing about this is that it allows us to efficiently couple an alternating current into the part while we are printing it, without hooking it up to electrodes. While the layers are deposited down, they are actively being welded together with that electromagnetic energy."

As the part is printed, you can watch the plasma dance across the part, lighting up the layers as they are hit with the energy. This is not only functional but also creates an interesting user experience. It is fun to watch, kind of like a plasma globe combined with a 3D printer, as can be seen for example in this video: <https://www.youtube.com/watch?v=1gy4NPesABU>

Vision for the future

With scientists and engineers all over the world taking away the limitations of 3D printing, where can this additive manufacturing revolution lead if we look a few decades into the future? According to Sweeney, the fundamental thing that additive manufacturing promises, is the ability to completely remove the creativity hindrances that have always plagued design and manufacturing: "The mechanical engineers of the world started out drafting designs, trying to create complex components. But everything came down to: how am I going to make this? Designers have always had to learn what a manufacturable part looks like. As additive technologies remove these constraints, you can just design the optimal shape and structure for the best properties. I am being a little dramatic, but I think that is where everything is headed. I think the future will be all about mixing polymers, ceramics, metals and composites in mixed material additive manufacturing techniques. Once that happens, electrical, mechanical and optical engineers will start to work collaboratively on designs. Instead of having an assembly of components, you will have an assembly of materials, fabricated in a one step process. Then if you can chop a consumer product up into layers, you can recreate it just by laying down successive depositions of every required material: glass, ceramics, polymers, metals... You could for example print a cellphone."

So, once we reach that point, the handcuffs constraining design freedom are taken away. "And then you are going to see a Moore's law equivalent happening in the rate at which we create new designs and hardware," Sweeney adds.

Mixed stream additive manufacturing

One of the key hurdles that must be taken away to make that possible is: being able to bond together dissimilar materials classes at random. That is not a simple problem, but according

to Sweeney in principle solvable: "We know fundamentally how to bond materials together so they are strong. That is not new science. It is just engineering being able to apply the physics necessary in order to achieve it. To do some of the grander challenges with additive manufacturing, I think it comes down to how to join materials that traditionally could not be joined together in the same environment. So, can I weld polymer layers together while also laying down a ceramic layer and fusing that together? To fuse a ceramic or metal you are talking about laser sintering for example. The temperatures at which those materials interact are well beyond the temperatures a polymer is going to degrade at. So, if you are going to come up with these truly mixed stream processes, we need to figure out new ways of bonding them together. I think it is very much going to be a chemistry problem. But look at the semiconductor industry for example.

They are probably the best example of an industry that has already figured out how to work extensively with polymers, semiconductors, and ceramic to metal interfaces."

Sweeney does not think that 3D printing and additive manufacturing are going to replace conventional manufacturing techniques: "I think they will complement each other. If you look around in your home, the vast majority of all objects in it have been injection molded. There is a reason the injection molding industry has become so commonplace: its ability to make useful items. And the thermoplastic materials it processes have amazing properties: they are reusable, and have a very high strength to weight ratio. So, I think it will keep a very strong hold on the market place. But I think that it will be complemented with these other, chemistry driven approaches where you join monomers to create specific compositions of polymers, metals or ceramics."

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Designing boats for the Volvo Ocean Race: An ongoing process of optimization and finding the right compromise

Django Mathijsen

Every three years, the best sailors in the world compete in the Volvo Ocean Race. For decades now, these sailing yachts have been sporting carbon fiber reinforced epoxy hulls. It was one of the first industries to adopt these materials. Reinforced Plastics talks to two of the people involved in designing these racers (Chris Cochran of Farr Yacht Design, and Guillaume Verdier) and finds out how it is done.

For the twelfth edition of the Volvo Ocean Race (in 2014/2015, [Figure 1](#)), the organizers decided to go from an open competition where every team could build their own boat within a set of rules (the Volvo Open 70) to a one-design competition where each team has to use the same design (the Volvo Ocean 65). Farr Yacht Design, which has a long history in the Volvo Ocean Race, as well as in designing one-design racing yachts, was chosen to design the Volvo Ocean 65, which is also being used in the thirteenth installment of the race (2017/2018).

Chris Cochran

Chris Cochran, Farr Yacht Design's senior design engineer, grew up racing on the Great Lakes in Michigan. "One of the few naval architecture schools in the country is also in Michigan," he says. "Once I found out about naval architecture and yacht design, I made it my mission to go to this school. When I graduated, I was fortunate enough to get a job in the yacht design industry. And after a couple of years, I was able to join Farr Yacht Design and went to work in the structural engineering department."

Working at a design bureau for racing yachts sounds like a wonderful job. And according to Cochran, people with a background in structural engineering and reinforced plastics, but no marine experience, still have a chance of getting into the business: "Yes, very much so. Especially if they have the ability to do Finite Element Analyses. That is one area which is becoming more and more prominent as an everyday design tool. Ten years ago, people might have only used FEA for very complicated or expensive projects with a lot of resources. Nowadays, FEA is used all the time. Having some marine background does help, mainly so you can understand the terminology. Boats have many

unique, quirky terms that are not used in other industries. So, having some knowledge of sailing or boating would help."

Examples of this quirky terminology are: "forestays", which are lines or cables from the bow to the mast heads to support the mast; "rig", which is another term for the mast; "chainplate", which is a metal plate bolted to the hull to fasten a stay. Some of these terms can be found at: https://en.wikipedia.org/wiki/Glossary_of_nautical_terms.

Resin Film Infusion instead of prepregs

"In order to minimize weight, they were all built with prepregs, mostly using unidirectional plies," Cochran says about the old Volvo Open 70, where every boat was custom designed and built. "There, the hull skins might be something like 1.5 to 2 millimeters thick and made of 150, 200 or 300 g/m² unidirectional carbon fiber at varying angles. So, it took a lot of time and effort to build the parts."

When the Volvo Ocean 65 was conceived, the goals set out by the Volvo Ocean Race organizers were to be able to build the boats in a shorter amount of time and make them more robust. The boats used the previous three races, the Volvo Open 70, had a fairly high failure rate, such that many boats did not finish legs in the 2012/2013 edition of the race. It was imperative that the VO65 would be reliable enough to complete every leg of the race. "The Volvo Ocean 65 one-design boat was not as weight-critical as a custom design," Cochran says. "And so, in order to reduce the labor hours, we used resin film infusion, primarily using Gurit SPRINT material. That still behaves like a prepreg, but the fibers are not pre-impregnated. The dry fiber is stuck to a layer of film adhesive. So, each ply, rather than being a unidi-



FIGURE 1

The Volvo Ocean 65 sailing boats, designed by Farr Yacht Design, on October 24, 2014 in Alicante, Spain. The same boats are used again in the 2017/2018 edition of the Volvo Ocean Race (Source: Photomarine/Shutterstock.com).

rectional prepreg ply, is a multidirectional, dry ply, attached to a layer of resin in a sticky form.”

There are two reasons why laying up is faster if you use RFI instead of prepreps. The SPRINT material is heavier and thicker: it already consists of several multidirectional layers. And where a roll of prepreps is typically 300 to 500 millimeters wide, the Sprint material is 1.2 meters wide. So, you can lay up wider surfaces and you need less passes.

Lightness versus strength

The challenge in designing a racing boat is finding the right compromise between lightness and strength. Cochran says that the boats stood up very well to the rigors of the race: “I spent a lot of time during the stop-overs inspecting each of the boats for damage, along with QI Composites, an NDT company. There was surprisingly little damage. When damage did occur, it was discovered that each of the boats had some unique problem that was more accidental than a design fault. For example, something was dropped from above, hit the hull and caused a little delamination which needed to be repaired. Or a tender hit a boat, resulting in a bit of damage on the outside. Other than that, there were very few issues associated with the composite structures.”

A few of the sailors did criticize that the Volvo Ocean 65 was a step back in performance, as Cochran explains: “A lot of them were just off the Volvo Open 70 (Figure 2), which was just about the most high performance monohull you could be on. And they were not necessarily aware of the tradeoffs between robustness, cost and build time versus the performance objectives that our client, Volvo Ocean Race, required from the design. So, their expectations were a bit too high.”

The composite structures were completely made using carbon fiber reinforced epoxy, with a few small exceptions. Methacrylate adhesives were also used for secondary bonding of structural components, and Sikaflex was used where non-structural parts were bonded and strength was not critical.



FIGURE 2

The Volvo Open 70 was just about the pinnacle in high performance monohulls. This is the Groupama team at June 10, 2012 at Lisbon, Portugal (Source: Milana Tkachenko/Shutterstock.com).

The laminate did not change from panel to panel on the hull, but the core thickness was varied in order to maximize performance or minimize weight. Most of the hull, deck and internal structures were cored using Nomex of densities ranging from 48 kg/m^3 to 96 kg/m^3 . The forward “slamming” area of the hull however has a foam core of GURIT® CORECELL™ M130. “For sailboats and powerboats, the forward underbody of the hull is susceptible to slamming in the waves while sailing upwind or downwind in big waves,” Cochran explains. “Those panels are subjected to very high peak loads as a result of those slamming incidents. Often an ocean racing boat will use a high elongation foam in the forward slamming area, which allows a lot of shocks to be absorbed by the core without breaking.”

The Volvo Ocean Race 65 weighs 12.5 tons. But the 8 boats that were built, all were within about 40 kilos of each other before corrector weights were added. “That is a hard feat to achieve for production boat building at any size, let alone at 65 feet,” Cochran says.

The hulls have four watertight bulkheads, which gives the boats five watertight compartments. “Plus a few smaller ones if you count the ballast tanks,” Cochran adds. “We design the boat so that if one or two compartments are flooded, some part of the boat is still above the water. For example, if a boat is sailing at 30 knots and hits a container, which is quite possible on the Southern Ocean these days, the bow area might flood with water. If the sailing team has isolated that compartment, per standard practice, the boat will not sink.”

The design process

“You start by looking at something similar you have already designed, getting an understanding of what is required, and looking for things to improve based on the objectives,” Cochran says. “Is the objective to make the boat cheaper, or to increase performance? Also, it is important to listen to feedback from people who are providing the design brief. Most of the time we are given certain parameters from the client. The boat has to be this long, accommodate this many crew, etcetera. You take all that

**FIGURE 3**

When going fast, the Volvo Ocean 65 does not have to plow through the water: it rides on the surface ("planing"), as demonstrated here by the Abu Dhabi Ocean Racing team (Source: Rick Tomlinson <http://www.rick-tomlinson.com/>).

information, think about it and start creating exploratory designs to come up with a solution. When a few different concepts have been evaluated, you start refining the solution."

The Volvo Ocean 65 is a non-foiling racing yacht, but the hull shape and canting keel do generate some amount of vertical lift. As a result, the boat will ride on the surface of the water – 'planing', Figure 3 – to some degree when going fast, mainly in downwind and reaching conditions. "There are pictures of the boat where the majority of the hull is out of the water," Cochran says (Figure 4). "The Volvo Ocean 65 is half of the weight of 'Steinlager II', the winner of the 1989–90 race, but sails with fewer crew and generates significantly more stability thanks to its combination of hydraulically canting keel and water ballast tanks. That big weight reduction without sacrificing stability results in substantial performance improvements. The VO65's achieved a 24 hour distance run of 561 Nautical Miles while boats of the 'Steinlager II' era struggled to break the 400 Nautical Mile barrier.

As the boat speeds increase into speeds more typically associated with motor boats – planing – the range of operating conditions the boat sees is expanded. The boat must operate well from very low to very high speeds at a wide range of heel angles and with a range of appendage – keel, rudder, daggerboard – settings. To insure the design is fast and responds well to changing conditions, we complete a large number of very detailed computational fluid dynamics simulations to refine the design and properly understand the performance potential."

In the automotive and aerospace industry, components are extensively tested before the design of the vehicle is finalized and goes into production. Full scale parts are built and tested until failure. That is not the case in the yacht world, as Cochran explains: "You are often pushing the boundaries of composites without doing all the expensive testing that aerospace companies have at their disposal. It is amazing to see what can be accomplished in the marine world using composites without any testing. You rely more on your computations and passed experiences than in other industries. It is maybe 70 percent past experience to give you a foundation. And the other 30 percent

**FIGURE 4**

On this picture of the SCA-team's Volvo Ocean 65 planing, it can clearly be seen that most of the hull is out of the water (Photo: Rick Tomlinson <http://www.rick-tomlinson.com/>).

comes from refinement using the tools. It is still common to validate material data through coupon testing, but overall structural loading on the boat is simulated using FEA."

Cochran emphasizes that you do not design a boat like the Volvo Ocean 65 on your own: "It was really a team effort with 20 designers and engineers, if you count all the subcontractors and additional composites engineers we brought in to help run CFD and FEA, perform the final engineering calculations, and create final drawings. Our timeframe was such that we had less than 6 months to go from rough ideas to issuing final geometry. And the one-design nature of the project meant that every part of the boat required a detailed 3D model and associated construction drawing. Over 1000 unique pieces of design information were created for this project."

Guillaume Verdier

For the fourteenth edition of the Volvo Ocean Race, the organizers are switching to a two-year cycle. So, the next race will be in 2019/2020. And the teams will be sailing on another one-design, for which Guillaume Verdier has been selected to be the designer of the monohull.

"I learned sailing at eight and used to do a month of sailing every year: at Easter and in summer," Verdier says. "So, I was passionate, but not in the racing world. What I find interesting is the technological aspects of the race. I started studying naval architecture in 1992 and specialized in composite materials. In 1992, most racing boats were already made of carbon fiber composites. The racing boat industry has always been quite innovative and fast in adopting exceptional materials like carbon or titanium, because they were always taking big risks: more risks than the airplane industry where it takes a long time before you get approval. I finished my master's degree in slamming for composite structures. And I started a PhD in Copenhagen in this field but did not finish it, because I was offered my dream job. I had been dreaming of getting into racing boats for seven years. In 1997, I was 27 years old, I started working at the drawing board in the design office of Finot-Conq for the

round-the-world single-handed yacht race. I learned a lot from Pascal Conq. In 2001, I decided to open up my own design office."

Verdier recently received an honorary PhD in technology from Southampton Solent University.

The virtual design office

Like Cochran, Verdier stresses that designing racing ships is very much a team effort: "I am one of the designers of the French entry in the America's Cup. There we are about twenty people designing together in a very horizontal structure."

Still, Verdier does not have a big office building. "It is all on the internet," he says. "The way we work is a bit like a platform of work sharing. I am usually organizing the work and I do some work myself. We are thirteen specialists, working with each other on computational fluid dynamics and modeling. We share the money and try to share the publicity as well. We help each other and I like to get the names of people that work with me known as well. So, they are keen to work with me. It is a unique way of working. For the Volvo, we have between fifteen and seventeen people sharing work. It is like a design office, but split all over. We try to see each other in meetings every week, at least the people who are not too far from where I live. Otherwise we do skype meetings."

One of the most important areas of technology in these racing boats is mechatronics. "A big part of the architecture of our boat now is to develop the software of the control system," Verdier explains. "Control systems like this exist in many fields, like rockets and planes, keeping them flying stable."

The boats are equipped with all sorts of sensors. Fiberoptics are bonded into the composites to measure the strain. The position of the waterline relative to the boat is constantly measured. And there are cameras and wind sensors. The heart of the sensors is a gyrocompass. "And then the software comes in," Verdier says. "You can display the information of how the boat should be ideally stable and then a human can move an actuator to locate it where the computer says it should be. The other option is to go full autopilot. Then the computer makes an actuator, like a hydraulic or electric ram, move. Autopilots are actually better than humans, but they are forbidden in racing. What is allowed is that the software tells the person what the ideal tuning of the boat should be, but it still has to be done by a person."

Monohull as well as multihull

The sailors are actually going to pit their skills against each other on two different boats in the Volvo Ocean Race of 2019/2020: next to the monohull, a multihull will be raced. Verdier explains why that is: "For safety reasons, the race around the world will be in monohulls just like before. If you capsize in a monohull, you can right the boat again. In a multihull, it is over. When you go around the South Pole there is a zone in the ocean where it is very difficult to rescue people. The Volvo Ocean Race organizers do not want to put lives at risk. The multihulls are used only for the inshore demonstrations. These are smaller boats that can be shipped so they do not have to wait for the last team in the race to enter the port. And the inshore parts with the multihulls will not interfere with repairs of the monohulls. Multihulls are faster.



FIGURE 5

The 100 foot "Comanche", designed by VPLP and Guillaume Verdier, set a transatlantic record of 5 days, 14 hours, 21 minutes, 25 seconds (Photo: Alvov/Shutterstock.com).

The record for crossing the North Atlantic is 3 days, 15 hours in a multihull. In a monohull it is 5 days, 14 hours. That is actually my monohull, the Comanche (Figure 5). The difference between the monohull and multihull (Figure 6) is getting smaller. Monohulls can fly over the waves as well. But in very rough conditions and extreme weather, you don't want to fly."

Now that the Volvo Ocean Race has a one-design for all competitors, has safety become more important than speed? "Yes," Verdier answers. "But on the other hand: if you make a boat that is not very exciting, none of the sailors will turn out for the race. So, Volvo insists that we make a boat that is cutting edge. You really have to make something that performs. The guys that come sailing are top sailors in the world. They do the America's Cup and extreme sailing. So, they do not want to go sailing in boring, slow boats."

To find the right compromise between making the boat safe and exciting is very difficult, but as Verdier explains speed and safety are not complete opposites: "Fast and safe are not always incompatible. For example, if you are fast, you can cheat the



FIGURE 6

Multihulls, like these yachts in the New York Harbor on May 7, 2016, competing in the America's Cup, are faster than monohulls. But a monohull is safer because it can right itself again after it has capsized (Photo: lev radin/Shutterstock.com).

meteorological system. If you see a low-pressure system coming, you just move away fast enough so you do not go into it. That is the safety aspect of being able to go fast. Everything we do is a compromise. You could be tempted to make a boat very heavy and strong. Because it goes through big waves and we would like to make it indestructible. But to make a boat go fast, it needs to be light. That is the biggest challenge. To make the boat strong and light enough."

Verdier's design process

Verdier's design for the Volvo Ocean Race has to be finished in February 2018. How does he tackle the job? "You start by making a specification of what people want," he says. "First questions are: when do you want this boat to be ready, how much is it going to cost and what is the size? The size of the boat and how many people they want to have on the boat dictates a lot of the design. Building ten 100-foot boats takes more time than ten 60-footers. You ask how they want to do the maintenance, what are their facilities? And why they want to change compared with the boat they had before. Maybe, they want the boat to be a bit more extreme, but with the same level of safety. So, you do a big specification that describes every aspect of what the design is going to be. A month or two later, you show them a pre-project: a computer model. And after some discussions we build a mockup of the deck and interior. Then the clients come and play on the mockup to see if the maneuvering on it is easy. We do a lot of simulations to show the boat's performance. In CFD you estimate the lift and drag of every part of the boat. And whether it is a sail, a foil, a hull or a rudder. We have software to assemble all these characteristics. So, we make a balance of all those forces and moments. And when you equate these at an instant of time you get the speed and stability."

Sustainability

Verdier uses a lot of high end carbon fibers like T800. Epoxy is used for laminating, except for a few areas where thermoplastics are used. For example, in the steering system of the dinghies: that

is a stick you hold in your hand. Thermoplastic resins are used to construct it in order to reduce the risk of it breaking and piercing someone's body.

He is very interested in new kinds of epoxy resins, for example with nanoparticles. And he likes to focus on sustainability. "The whole point of what we do is to show you can cross an ocean with no fuel energy," Verdier says. "But making a boat from carbon fiber composites is not very clean from an environmental point of view. People are getting more and more concerned about that. If for example you build a 30 meter long boat, you have to build a 30 meter long mold, which is about 5 millimeters thick in carbon fiber. That is tons and tons of carbon fiber. So, it would be good if we could make things more recyclable. Most of the industry today is epoxy resins. Maybe, you could use PEKK, a thermoplastic resin, for the mold, which could then be recyclable."

There are already some initiatives to recycle parts of the boat, as Verdier explains: "A sail for a boat is now a membrane of carbon with a soft resin. The best way to recycle that, is to use it to build furniture and to make souvenirs for the luxury market. At least that is something. But for the hulls: they do not manage to sell a slice of boat to everybody. Volvo are truly concerned about that. They clearly see the future in being clean and they push us to be sustainable. We have to be an example for our industry. So, we put everything on the table, from construction to electricity generation to recycling the mold. We have for example an engine in the boat to generate electricity for telecommunication and such. That is also a safety factor. So, we have a person in our team now from the Safran Group, who is specialized in electricity generation in space ships."

Verdier dreams of convenient ways to separate the epoxy from the fibers, to make the carbon fiber composites more recyclable. For example, bacteria that eat the epoxy. "I have not seen it, but I am sure people are working on that," he says. "I would be so glad to see that happen: you open the trash, throw in the bacteria and they eat the epoxy. They are using bacteria for separating gold from mud. So, it should be possible."



Prospects of wet-laid nonwovens for organosheet-products

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Using the paper process to obtain short-fiber-based reinforcements.

Rising energy and raw material prices have made lightweight components an increasingly attractive alternative, especially for vehicle and aircraft construction. Fiber-reinforced (thermo-) plastics or polymers (FRP) make it possible to meet the present requirements for resource conservation and CO₂ reduction. They are manufactured from high-performance S-glass, basalt or carbon fibers. Therefore, the amount of FRP waste from manufacturing and at end of their life will increase drastically and in particular needs to be considered for carbon fiber reinforced plastic (CFRP). Research is dominated by the quest for techniques to regain the fibers from (C)FRP waste. While dry carbon fiber waste (from cutting, stamping, etc.) is mainly treated mechanically to regain fibers, wet waste has to be recycled via pyrolysis or solvolysis. So far, only pyrolysis-based recycling is realized in industrial scale. Both options lead to fiber fractions with limited and various fiber length, mainly <60 mm. Therefore applications for those recycled fibers needs to be identified, hence, this paper focuses on the transformation of recycled fibers into a sheet material. Furthermore the fibers resulting from the pyrolysis are weakened and brittle after the high temperature treatment and tend to shortening and dusting during further processing. For this reason the wet-laid process is an appropriate route of transforming short reinforcing fibers, for example, recycled carbon fibers, in a processable raw material – a nonwoven. As mixing of the fibers takes place in aqueous solution, hereby fiber shortening is decreased and dusting is minimized as long as there is residual moisture content.

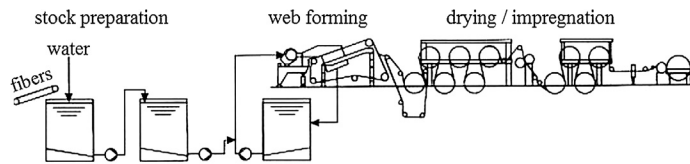
Wet-laid process

The manufacturing process for wetlaid-nonwovens is derived from the papermaking process. The process may be used to create webs of all types of fibers which can be dispersed in fluids. Basically the process consists of three main stages: (i) the dispersion of the fibers in water, (ii) web formation and (iii) drying/impregnation as depicted in Figure 1.

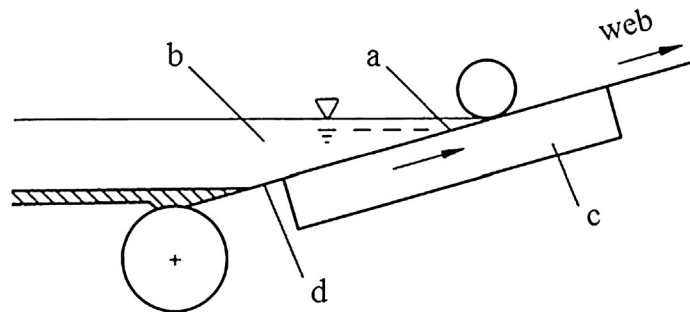
During stock preparation short fibers (generally <30 mm) are dispersed in water, frequently together with cellulose pulp (acting as a binder) to give a dispersion with a density of 0.1–0.8 g/l. This concentration is ten times more dilute than that used for paper manufacture to assure a uniform fiber separation. Continuous web formation is achieved by the fibers being deposited onto an inclined screen. Water is then uniformly sucked off over the machine width through suction boxes located beneath the screen. Deposition of the fibers on the screen is controlled by the filtration resistance of the web that builds up during the process. The principle is highlighted in Figure 2.

Fiber orientation can be regulated partially by adjusting the web-forming speed and the suspension rates. A randomized web is formed if the two rates are the same, whereas a difference in the rates favors the formation of a unidirectional web. As a result the materials are non-isotropic. The two resultant main directions are called 'machine direction' (MD) in flow direction and 'cross direction' (CD) orthogonally to it. The minimum requirement for 'consolidation' of the nonwoven is drying of the web by means of a suction drum or can dryer. Cohesion of the web is a result of fiber to fiber friction (entanglement) or chemical bonding by means of a binder. The binder can be precipitated on the fibers (preferably cellulose pulp) prior to web formation by coagulation in the mixing vat. Binders are, however,

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**FIGURE 1**

Set-up and main production stages of the wet laid process according to Pill and Afflerbach [1].

**FIGURE 2**

Principle of web forming on an inclined screen: (a) inclined screen, (b) suspension, (c) suction box, (d) suction-free zone; according to Fahrbach et al. [2].

usually applied by spraying, padding, foaming, screen printing, or saturation – the impregnation – prior to final drying.

The process itself and the subsequent transformation in a composite show high potentials and severe restrictions at the same time. Economic production and good processability and good surface appearance are some of the advantages. One very important advantage is the ability to mix reinforcing fibers with thermoplastic matrix fibers in ‘one step’. On the other side limited fiber volume content and limited drapability are its main backdrafts.

Hence, it makes sense to combine wet-laid nonwovens with other reinforcements, for example, airlay nonwoven or UD-tape to tailored hybrid composites. This approach was considered in several public funded research projects, which will be introduced shortly in the following paragraph.

Development of hybrid carbon fiber reinforcements for organo-sheets (‘FullCycle’)

PTS (Papiertechnische Stiftung, Germany) was collaborating in the ‘FullCycle’-Project (IGF-Reference 18717BG) with ITA (Institut für Textiltechnik, RWTH Aachen University, Aachen, Germany) and LCC (Chair of Carbon Composites, Technical University of Munich, Munich, Germany) to develop hybrid carbon fiber nonwoven reinforcement structures for organo-sheets. Goal of the project that started in 2015 was to combine an airlay-process and a paper-process to produce a hybrid isotropic reinforcement structure on C-fiber basis and to use the full spectrum of fibers supplied by the recycling industry. Key idea to this process is to combine a nonwoven process with strength in short fiber handling and a nonwoven process with strength in long fiber processing. Considering all available nonwoven process

variants, there are many possible process combinations available. Thus, the process choices were derived from the targeted application field. Actual developments in the transportation sector show, that multi-material solutions offer the largest weight saving potential. In these solutions, metallic components are substituted by composite parts. Thus, the novel material which results from the combined – a hybrid nonwoven layer reinforced composite – is targeted to be a substitute material for metal sheets in surface applications. This choice results in the combination of a paper and an airlay nonwoven process, to create an isotropic structure leaning on isotropic metal structures. This process combination enables the layer-wise design of staple fiber reinforcements for organo-sheets. Long fibers and directed structures can be placed in layers with high expected loads, while short fibers can be added for surface design and bending flexibility. Carbon fiber waste (CFW) and short fiber sections are processed into a carbon paper. This paper can either be applied as a highly homogenous surface layer to enhance the optical and haptic perception of the product by customers. Otherwise, the paper can be supplied as a central layer to ‘store’ CFW pulp in a composite. Long fibers are processed by the airlay process to add strength to the composite. These long fibers are mixed with matrix fibers into a mixed nonwoven. Finally, several layers of these nonwovens are stacked and heat pressed into an organo-sheet. The mechanical performance of a hybrid reinforced PA6-organo-sheet was with round about 25 GPa tensile modulus comparable to what is known from literature [3]. Additionally the integration of functions into the hybrid structure was explored. Since the CFW based structure is electro conductive but shows a certain electric resistivity, the current investigations focused on the generation of heat. By including copper wires into the organo-sheet, a voltage could be applied. Due to the isotropic structure of the material the heat generation was very uniform, which could be used for example for panel heating. Future research by the authors will focus on optimizing the multi-layer nonwoven structure. The qualitative impact of different layer setups will be investigated as well as the impact on the heat development and distribution in the nonwoven sheet. *The project was funded by the German Federation of Industrial Research Associations – AiF.*

Joint research project of STFI, Cetex and PTS about new lightweight materials (‘HyBaVli’)

The Saxon textile research institute STFI, Institute for textile and converting machines Cetex and Papiertechnische Stiftung have launched a joint research project with the acronym ‘HyBaVli’ (ZIM project Reg.nr. 16KN021655) to develop structural components based on high-strength, well drapable materials made from basalt fiber-reinforced thermoplastic UD tapes and hybrid basalt nonwovens. Aim is to substitute basalt for the fibers commonly used in these components. Basalt fibers are made from crushed basalt stone, preferably from a basalt of high acidity and low iron content. The raw material is washed and then melted, no additives are needed for the spinning process. Their favorable mechanical properties make basalt fibers a cost-efficient alternative to other high-performance fibers.

When developing the hybrid nonwoven, it was decided to use needle punching as dry compacting process, with basalt fibers of

**FIGURE 3**

Wet-laid Basalt-PA6 nonwovens.

**FIGURE 4**

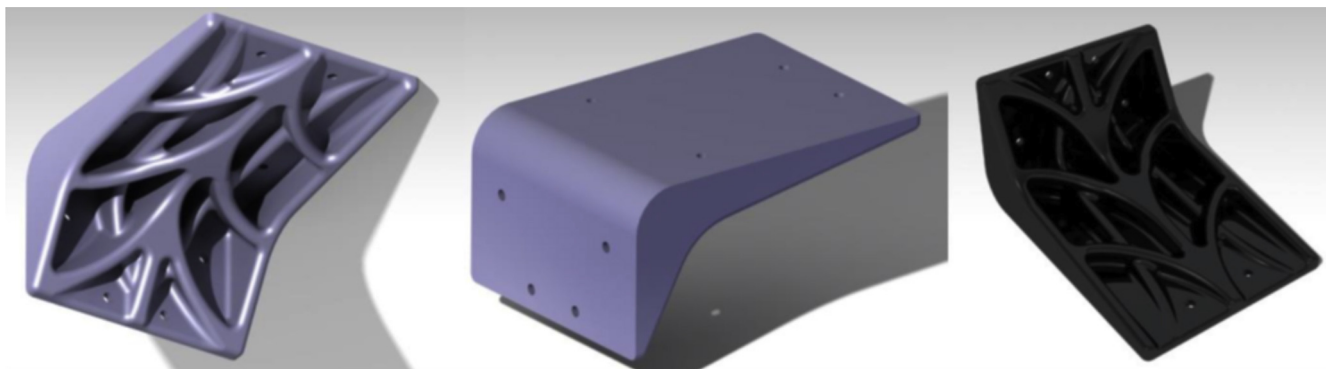
Micrograph. Source: Cetex.

three different lengths (50, 80 and 110 mm) and thermo-plastic polyamide fibers (PA6, 3,3 dtex/60 mm). The basalt fibers were cut to the desired lengths at the company Fibtex GmbH in Rovings. To identify the optimum mass shares for thermoplastic fiber composite components, the basalt fibers were mixed with PA6 fibers in mass shares of 40%, 50%, 60% and 70%. The second approach was the wet-laid process: PTS used the inclined wire module of its pilot paper machine in Heidenau to produce hybrid nonwovens with the above-described fiber compositions. The basalt fibers had to be cut to lengths suitable for the wet laying process (6, 12, 18 mm), and also PA 6 fibers (6 mm, 1,9 dtex) were used as thermoplastic fibers (Figure 3).

Cetex develops suitable process parameters to turn the hybrid nonwovens into organic sheets. For this purpose, the nonwovens are compacted in a static press by means of a special pressure-time regime. The converting parameters must be adjusted to the fiber mass shares used in each specific case to optimally impregnate the reinforcement fibers and minimize the porosity of organic sheets. The measurement of mechanical properties by standard test methods shows afterwards if the chosen mass

shares and fiber lengths were really optimal. The basalt fibers in hybrid nonwovens must be completely wetted with the matrix material to achieve optimal mechanical properties. For this purpose, a polymer (PA6) bound in the hybrid nonwoven material is melted under heat and pressure in a hydraulic laboratory press, using optimized process parameters, and then left to cool off. The treatment results in a fully impregnated flat organic sheet. Micrographs have shown that the above described pressing step leads to a satisfactory basalt fiber impregnation with only isolated small air inclusions in the organic sheet. Next, continuous basalt fiber reinforced UD tapes were pressed onto the hybrid nonwoven- organic sheets. Subsequently acquired micrographs showed that the connection between nonwoven and tape materials was of a very high quality (Figure 4).

The method makes it possible to systematically adjust the mechanical properties of components to the stresses and loads of their future applications. The structural components obtained will be used to identify and verify the application options and

**FIGURE 5**

Structural component developed as demonstrator. Source: Form+Technik.

limits of the new material combination. Based on the project aim, the components should meet two main requirements: (1) low-stress areas with high degrees of deformation, reinforced by hybrid nonwovens; (2) high-stress areas, reinforced by UD tapes. An aggregate holder developed as demonstrator in the present work package meets these requirements. Its basic structure is an angle section reinforced with various ribs that simulate a biotic structure (e.g. leaf structure) on the inside. By varying the width and depth of ribs, it is possible to determine the potential flow limits of the fused-on material in the forming process (Figure 5).

The project results can be used to provide especially customers in the automotive and aviation sectors with interesting new materials.

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Developing enhanced carbon nanotube reinforced composites for full-scale 3D printed components

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Recent research has developed a range of novel nano-enhanced 3D Printer filaments for high-end structural applications. In this research, an enhanced carbon nanotube filament has been formulated with different concentrations of graphitized multiwalled carbon nanotubes. These have been dispersed into an acrylonitrile butadiene styrene polymer matrix under a process of high sheer mixing. This formulation was extruded to form a 1.75 mm diameter filament that was used to 3D print custom full size aerospace components that were later tested and displayed mechanical strength enhancement. In this article the process is detailed which show a method to manufacture 3D printed nanocomposite structures. These polymer filaments can be used on any conventional fused deposition modeling 3D Printing machine for the fabrication of scale components that require mechanical enhancement.

This evolution in enhanced polymer 3D printing filaments allows inventors to produce custom circuit boards, electronic devices, game controllers and custom structural parts [1]. Although this novel type of 3D printing requires slightly more skill due to difficulty in their handling, these materials are now within reach of everyone [2].

The first generation of enhanced filaments used the monomer polycaprolactone (PCL) mixed with conductive carbon black powders [3]. This later evolved into conductive Acrylonitrile butadiene styrene (ABS)-based carbomorph materials that instigated a revolution in home-built consumer electronics fabrication [4]. These 3D printable materials have been investigated as method to produce simple yet important integrated machines, that can be used to detect:

- changes in temperature;
- when water is placed onto a surface;
- applied pressure;
- whether a device is being flexed.

When these actions happen, a difference in electrical resistance is detected. What this means is that devices can now be 3D Printed with integrated functionality which has never before been possible [5]. Further enhancement has been made by adding short

discontinuous lengths of carbon fiber into a polymer matrix to improve structural integrity [6].

Further to this, conventional 3D printing filaments and enhanced filaments can be integrated together in different layers to make multifunctional parts [7]. This advance in low-cost 3D printed, offers the possibility of producing sensors and electronics embedded inside structural 3D printed objects. The uniqueness of this is that devices can be fabricated in a single build. However, one of the major setbacks in enhanced 3D printing filaments is that due to the relatively high concentrations of additions required to reinforce the polymer matrix. This subsequently reduces printability, blocks the nozzle and reduces adhesion to the build platform. Because of this, these formulations are impractical.

During this current research, the objective is to develop a nanostructured 3D printing filament with low concentration additions of MWCNT. These are used to selectively reinforce the underlying polymer matrix at the nanoscale. Due to the high percolation threshold of nanotubes then this results in structures that have complete interconnectivity across the matrix.

In order to generate the filament material, bulk formulations of a test polymer were produced by first dissolving ABS pellets into 2-butanone solvent to form a liquid phase polymer. Mixing

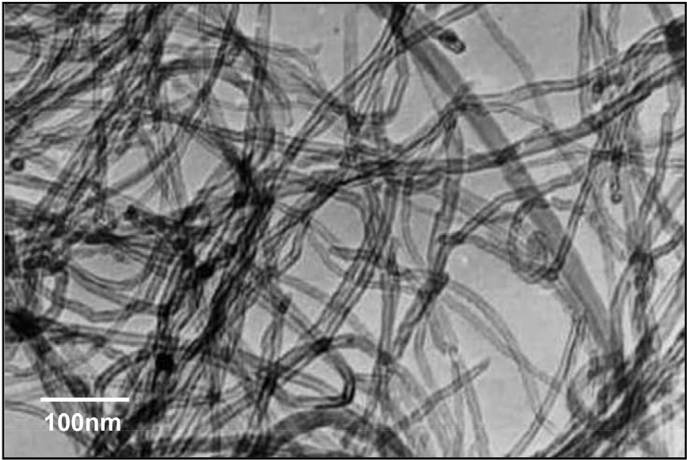


FIGURE 1
TEM image of 10–30 nm diameter MWCNT.

was then carried out using high shear impeller mixing at 2000RPM for 4 h to prepare the liquid polymer. Graphitized MWCNT's are shown in the Transmission Electron Microscopy (TEM) image in [Figure 1](#) were added to the polymer. Graphitized MWCNT 20–30 nm were produced by Catalyzed Chemical Vapor Deposition at 2800 °C to graphitize them. The recorded properties of the MWCNT are displayed in [Table 1](#). Mixing was carried out at 1000RPM for a further 4 h to ensure equal dispersion of the MWCNTs into the matrix. The mixture was then placed into an oven at a temperature of 80 °C for 12 h to remove any remaining solvent and repolymerize the nanostructured enhanced ABS.

The resulting nano-enhanced polymer was then shredded into a 1 mm diameter pellet form and then left to stand at room temperature for a further 24-h. To make the 3D printing filament, an extrusion stage process was undertaken. This involved extruding the pellets down to 1.75 mm diameter continuous filament at 135 °C ± 2 °C using a hopper and lead-screw with was used to mix, heat and extrude the filament.

TABLE 1
Properties of graphitized MWCNT.

Property	Measurement	Unit
Outer diameter	20–30	Nm
Inside diameter	5–10	Nm
Purity	>99.9	wt%
Length	10–30	µm
Specific surface area	55	m ² /g
Electrical conductivity	>100	S/cm
True density	~2.1	g/cm ³

TABLE 2
Concentrations of MWCNT (wt%) into ABS.

Content MWCNT (wt%)	Matrix Material
1.0	ABS
0.75	ABS
0.5	ABS

TABLE 3
3D printing process parameters.

Printing parameter	Value	Unit
Layer thickness	100	µm
Print speed	50	mm/s
Number of shells	4	–
Temperature (extruder)	235	°C
Temperature (build platform)	120	°C
Diameter of extruded plastic	400	µm

The different concentrations of MWCNT that were mixed into the ABS matrix are shown in [Table 2](#). 3-D printing of the nanocomposite filament was carried out using a 3Dynamic Systems Delta FDM printer. This device was used to deposit the material to a layer resolution of 100 µm and allowed the fabrication of large real-world components. The parameters used to 3-D Print test samples and full sized components are shown in [Table 3](#).

A series of 3D prints using each of the filament formulations was carried out to generate test structures that would act as a reference to analyze the dimensional accuracy of the nanocomposite post 3D printing. This full-sized structure is shown in [Figure 2](#) displayed good adhesion to the build platform, linear accuracy of ±0.75% and curved accuracy of ±0.8°.



FIGURE 2
A 3D printed nanocomposite full size aircraft wing rib produced to test the dimensional accuracy and a 3D scan showing the layer resolution of the structure with 1% MWCNT.

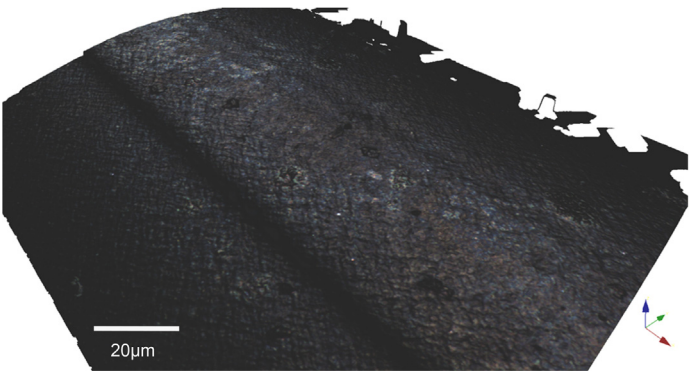


FIGURE 3
3D WLI topographical scan of a single layer showing the morphology of the surface structure.

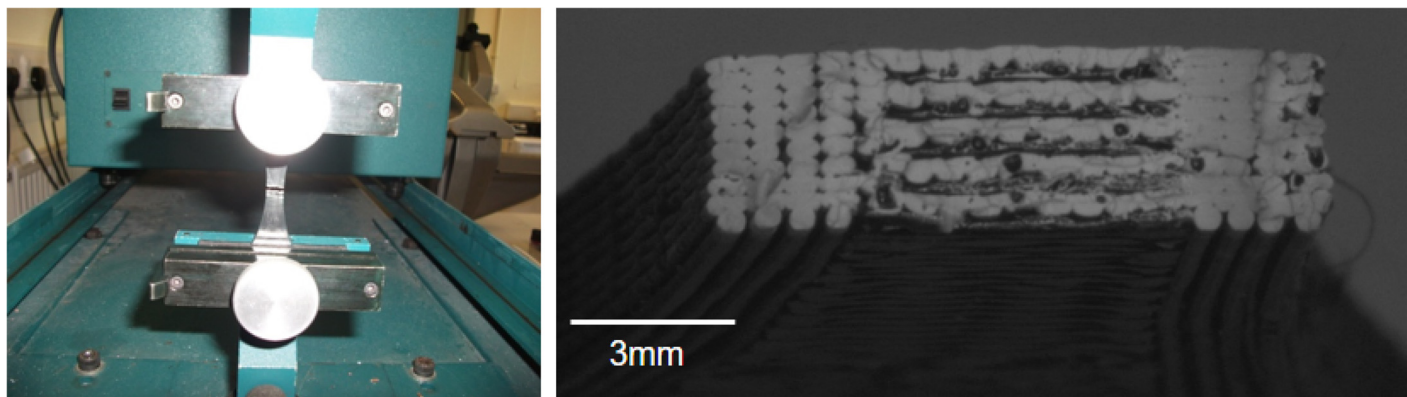


FIGURE 4

Mechanical test and SEM images taken of the fracture cross section of the 0.75% MWCNT nanocomposite.

Figure 3 shows a WLI scan of a single 3D printed layer. Under high magnification the morphology of the nanocomposite was observed in detail. Here the structure shows that a completely homogeneous structure was formed and that the effect of MWCNT's is of no negative effect towards the print.

The importance of nanocomposite architectures is that due to the increased surface area induced when the MWCNT are added to the matrix polymer. However, as the concentration of MWCNT is increased then this also increases the glass transition temperature of the nanostructured polymer. The knock-on effect of this is that a higher nozzle temperature of 235 °C is also required during the 3D printing process.

The 3D printed dimensional resolution of a nanocomposite was measured with the structure being only 1.8% smaller due to the shrinkage of the ABS matrix as during cooling. Analysis of the printed layers was subsequently carried out in order to understand how the material fuses together during the 3D printing process. A deposition temperature 235 °C was used during the 3D printing process in order to fuse the polymer layers together correctly. White Light Interferometry (WLI) scans taken of the 3D printed architecture in which the repeatability suggests that low concentrations of MWCNT do not appear to influence the layer quality of the print produced.

Smaller 3D prints produced and tested shown that the fractures generated after mechanical testing are shown in Figure 4. It was observed that there is a degree of ductile fracture surface. These observations indicate that the increased surface area that the MWCNT hold the polymer together under tension and increase the yield point of the material.

The surface of the fracture shows the internal 3D printing architecture generated in which the longitudinal 3D printed shell structure would take up more of the strain. This is because it is a continuous filament with no layer adhesion in the line of stress to hold the structure together.

As shown in Figure 5, when comparing the different formulations, it was observed that the 0.5% MWCNT nanocomposite had a significant loss of mechanical strength over the parent material. However, the elongation was increased by 714%. The elongation also increase by 863% when using 0.75% MWCNT and 1104% when using 1% MWCNT in comparison with the

base ABS Polymer. Strength also increases significantly over the parent material by 5.5 MPa and 8.5 MPa for 0.75% and 1.0% concentrations respectively. These results show that there is a significant improvement in the properties of the nanocomponent filament formulations.

This concept allowed for the first commercial 3D printed components which can be used for lightweight and minor structural applications. The structural enhancement of the nano-enhanced filament allows the structure to have a reduced size parts to allow for weight saving. Also features can be created which are more flexible and subsequently durable. During 3D printing the layer adhesion did not display any reduction over that of parent ABS.

This research work has shown that there is potential of nano-enhanced polymers for 3D printing. This is particularly the case of 3D printing materials that have enhanced properties, but also which have no difference in printability over traditional polymers. Rather than there being a brittle polymer fracture as usually found in conventional ABS. The nano-enhanced polymer is instead ductile. This indicates that due to the addition of

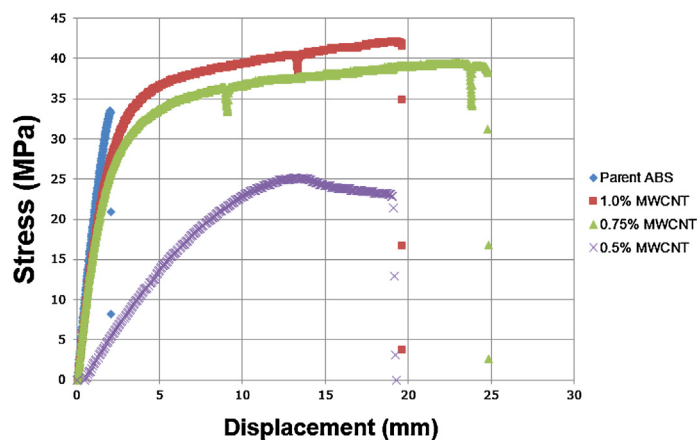


FIGURE 5

Mechanical strength properties of 0.5%, 0.75% and 1% MWCNT enhanced nanocomposite in comparison with parent ABS at a loading speed of 0.1 mm/min.

MWCNT then there is increased binding surface area of the polymer which inhibits fracture under tension.

After testing the 3D printed mechanical test coupons then interesting observations were made of the subsequent fracture. Here the nano-polymer displays significant increases in elastic deformation prior to subsequent fracture. It is this property of the nanocomposite which gives this material its most significant and useful enhancement. Further to this, the effect of the tension speed also has an effect on the polymer work-hardening. At concentrations of 0.75% and 1% then the resulting nanocomposite displayed structural enhancement. This indicates that there is a good balance between the MWCNT concentration and polymerization.

The nanocomposite filament is mechanically stronger than conventional ABS. Nanostructured polymers such as the formulations reported in this study have a wealth of future uses. The following conclusions can be drawn from this work:

- Due to the high percolation threshold of MWCNTs. Nanocomposite 3D printing filaments can be formulated that show no reduction in printability.
- The combination of 1% MWCNT in an ABS polymer matrix resulted in the formation of a nanopolymer which displayed optimum mechanical properties under tension.
- Nano composite 3D printing polymer filaments and their architecture show great promise for the development of future integrated devices which require enhancement for very little increase in cost.

Nomenclature

ABS	acrylonitrile butadiene styrene
MEK	methyl ethyl ketone
MWCNT	multiwall carbon nanotube
nm	nanometer
TEM	transmission electron microscopy
wt%	weight (%)
UTS	upper tensile strength

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PVC-O pipe innovations

Cristina Onieva, Almudena Blázquez

Molecor, a Spanish company founded in 2006, is the current leading company in the development of the Molecular Orientation Technology applied to water under pressure canalizations. Its genuine and exclusive technology has allowed the company to launch innovative developments over the years into the market that nowadays it is considered one of the most important referents of growth, continuous improvement and internationalization.

The success of Molecor's technology is not only based on its pioneering character but also demonstrated by its incredible results. It consists of a completely dry and clean air system that distributes the air in a specific way to achieve the maximum degree of orientation, replacing boiling water used in other manufacturing processes. This new system developed by Molecor allows manufacturing Class 500 PVC-O pipes with better mechanical properties and therefore a higher quality final product: TOM[®] pipes (Figure 1).

Due to the research and development in which the company is immersed, and thanks to its commitment to innovation, Molecor has been able to develop multiple systems. Each of them has become a turning point in its sector since it has contributed and allowed the company to overcome obstacles in PVC material.

Among these developments is the M-OR-P 3163 system which was presented in 2010. The novelty of this system was its capacity to manufacture PVC-O pipes up to DN630 mm. It was the first time that a company was capable of manufacturing PVC-O pipes with this diameter. However, not satisfied with this, Molecor presented the M-OR-P 3180 System just three years later, a system with which the company became the first company capable of manufacturing the largest PVC-O pipes. In this case we are talking about DN800 mm PVC-O pipes capable of enduring nominal pressures up to 25 bar.

The Integrated Seal System and the Integrated Socket System are two other important milestones achieved by the company. The first one enables a rubber gasket to be inserted inside the pipe in a completely automatic way, ensuring a complete and perfect attachment. This development is one of the most impor-

tant milestones developed by the company since this technology has never been applied to PVC-O pipes before.

The Integrated Socket System allows the production of the socket, the most important part of the pipe, while the rest of the pipe achieves optimum conditions for the molecular orientation. In addition to the stability and simultaneity of the process, Molecor's technology achieves different degrees of orientation in the required sections of the socket.

The enormous success of Molecor's technology is explained by its multiple advantages. Instead of boiling water, the use of air prevents possible leakages and the consequent burns that the operators could suffer. It is also a stable system since it presents a fully automatic control center that allows disconnecting the machine in stages, preventing the collapse of the line in case of punctual failures.

A standard PVC extrusion system allows the manufactured pipes to meet the specific needs of each customer. Furthermore, it only uses the necessary amount of energy for distributing the air through the pipe, and has an electrical consumption similar to conventional extrusion lines. Molecor's exclusive technology enables the manufacturing of PVC-O pipes with the greatest degree of orientation, Class 500, achieving savings of around 50%. Furthermore, the improved quality of the product extends its useful life. All these facts lead to significant savings in raw materials and other costs. The different systems developed by Molecor have enabled the company to manufacture not only the largest PVC-O pipes but also the most eco-friendly ones.

PVC-O pipes are not easily destroyed by regular impacts that take place during their manufacturing and installation. In

**FIGURE 1**

TOM® PVC-O pipes.

addition, the layered structure achieved with the molecular orientation process prevents crack propagation and scratches. When cracks appear, they progress through the amorphous wall structure. In PVC-O pipes, these cracks remain on the first layer, not affecting the pipe's properties at all. The result is an increase in product life.

PVC-O pipes also offer resistance to internal pressure up to two times the nominal pressure, which means they can endure a sporadic excess of pressure such as water hammers in the network. Moreover, the material creep behavior is very low, ensuring the durability of the pipe working at nominal pressure for over 100 years.

The Class 500 PVC-O pipes manufactured by Molecor considerably enhance the hydraulic capacity of the pipe, ranging from 15% to 40%, depending on the material and diameter with which it is compared. Furthermore, load losses are much lower due to the extremely smooth inner surface of the pipe, which means that water can be conveyed at a higher speed. Consequently, the capacity of the network is also higher, minimizing energy consumption and CO₂ emissions.

PVC-O pipes can bear big deformations of their internal diameter thanks to their excellent elasticity. When crushed, or in the event of a mechanical accident, TOM® pipes immediately go back to their original shape, thus minimizing the risk of potential breakage, for example by soil subsidence or sharp edges on rocks or machinery. Furthermore, due to their considerable capacity for bearing heavy loads, TOM® pipes ensure optimum performance once underground.

TOM® pipes also offer lower celerity than other piping systems (four times less than ductile iron pipes), which means less water hammers caused by sudden variations in water volume and pressure. This reduces and, almost eliminates, the possibility of breakage during opening and closing in the water network and when pumping gets under way, protecting every component of the network.

Despite of all these developments and its enormous contribution to its sector, Molecor is aware of the necessity to continue improving and investing in new projects. EcoFITOM® fittings are the latest project in which the company has made a huge

investment. It consists of the development and manufacturing of the first fittings in PVC-O with which the company offers a continuous solution in PVC-O. These fittings present multiple advantages in terms of performance, savings, sustainability and installation, as with the TOM® pipes, since they are manufactured with the same technology.

EcoFITOM® fittings with non-discontinuity ensure water tightness; reduce breakages, leakages and failures in comparison to other systems. EcoFITOM® is also immune to corrosion and to chemical attacks from micro and macro organisms. The quality of the conveyed fluid remains unaltered in compliance with health standards for water's human consumption. EcoFITOM® also reduces water hammer by up to four times compared with other materials. The molecular orientation process also makes it possible to manufacture PVC-O pipes with a greater internal diameter and flow section.

The excellent mechanical properties of PVC-O enable a significant reduction in the use of raw material compared to other products with the same physical requirements, reaching important material savings. The energy consumption needed in the manufacturing process is slightly lower than other PVC-O pipe manufacturing processes and considerably lower than other plastic pipes. The petrol consumption needed to manufacture the raw material is lower than for other plastic conduits. No protection or coating is needed vs iron. There are also many savings in production, installation and maintenance processes.

EcoFITOM® preserves the environment, considering aspects such as energy saving, or sustainable use of natural resources, among others. More than 50% of PVC resin is made of chlorine, derived from common salt, which significantly contributes to non-renewable resources savings. It can be also be recycled, as it is used not only for new piping production, but for urban furniture, road safety elements, window profiles, sound proofing panels, and more.

PVC-O pipes are lighter and easier to install than other materials. No machinery is required to handle them since it is between 6 and 12 times lighter than ductile iron. The efficient socket design also provides a robust rubber sealing ring and faster connection between pipes and fittings; the plug-in limit mark

**FIGURE 2**

EcoFITOM® fittings.

facilitates installation and ensures their correct assembly. Furthermore, the PVC-O is durable and prevents leakage of channeled water, as well as ensuring a life of over 50 years, versus other materials which last 30 years. They are also easy to assemble since there is no need for welding. Its weight allows higher performance and installation speed compared to the rest of the materials (Figure 2).

With these fittings the company will offer a totally innovative solution for the conveyance of water under pressure. They may be used for irrigation, drinking water, industrial uses, sewage water, infrastructure, fire protection nets, among other applications. These fittings, compared to products made of other materials, present an important number of advantages.

Molecor's commitment to the environment is clearly noticeable in its products, the most environmentally friendly solutions existing on the market due to their contribution to sustainable

development, as has been demonstrated by different studies worldwide. TOM pipes present environmental benefits at all stages of their lifecycle, thus resulting in the highest energy efficiency. For these reasons, TOM[®] pipes have received the eco-label Environmental Footprint FVS Seal, promoted by the Sustainable Life Foundation and the General Directorate of Social Responsibility of the company's Ministry of Employment and Social Security.

Molecor follows an Integrated Quality and Environment Management System based on the UNE-EN ISO 9001:2008 and UNE-EN ISO 14001:2004 standards, for the "Manufacture of PVC-O pipes for conveyance of fluids under pressure". Finally, TOM[®] PVC-O pipes are manufactured in accordance with ISO 16422:2014 standards, applied to "Pipes and joints made of oriented unplasticized poly (vinyl chloride) (PVC-O) for the conveyance of water under pressure".

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Expert insights in Europe's booming composites market

FEATURE

Michael Effing

Chairman of the Board of Composites Germany and AVK, Founder and Managing Director of AMAC GmbH

Composites are a dynamic, high-volume growth industry in Europe.

Europe is an important location, among others, due to its very specific and efficient cooperation and joint technological developments between research and industry. From country to country, the industrial organization as well as the research landscape varies. In this highly sophisticated production technology environment, complex materials and often multi-material technologies are constantly developed and improved, which enables automated mass production and advanced lightweight technologies to stay in high wage countries. In this context, Germany figures as a leading supplier for lightweight applications, with enormous strength in the manufacturing and mechanical engineering sectors, many strong and successful SMEs and numerous OEMs in all end markets present on the market. Key segments are traditionally automotive, aerospace, and electronics, but there is also a focus on wind energy and building and construction (Fig. 1).

Traditionally, the transport sector with aerospace and automotive represents more than a third of the market. The B&I sector represents almost the same proportion, with a value in Europe of 8 billion euros, and where approximately 900,000 tons of composite materials are used. Examples of how composites can be used in the building industry can be seen by the Dubai-based Company AFFAN, which is making a large variety of buildings, ranging from large entrance areas of skyscrapers to complete logistic centers, museums, and even private villas in composites, using resin infusion and prepreg technologies with carbon and glass fiber reinforcements. While in the Middle East and Asia, the restrictions and standards are not as tight as in Europe or in Germany, it is expected, that the market, specifically in these regions as well as in South America, will grow even faster than in Europe. The most advanced use for composites in infrastructure is actually the rotor blades for wind turbines and the composite pipelines and vessels (Fig. 2).

Research and industry working shoulder to shoulder

Specific to the German market is the close cooperation between research and industry. For example, at the Campus of RWTH Aachen University, research institutes cooperate closely with industrial partners in a pre-competitive way in order to drive innovation and further develop cost-effective, integrative, high-volume production technology. In June 2017, the AZL partner network counted over 80 industrial partners which are cooperating with 9 research institutes on the Campus, which are linked to lightweight technologies. Under the auspices of AZL, joint studies are being carried out with the aim of identifying new applications or market opportunities for specific technologies or, the other way round, new and often multi-material technologies for specific applications. Joint partner projects are also being carried out, in which 10–15 companies share the cost of new pre-competitive developments, such as developments of key processes like thermoplastic composites, high-speed RTM, or pipes and vessels. Another focus is on finding out new possibilities for using high-performance SMC. HP-SMC means composites are made of various fiber reinforcements, from carbon to glass, with continuous and discontinuous fibers as well as various new resins, such as polyester, vinyl ester and epoxies, opening the door for more structural applications in the automotive industry, such as floor pans, as well as new applications for high-speed trains and other transportation. This SMC workgroup has also requested AZL to perform a market and technology study for the development of design guidelines for HP SMC.

Another study focuses on identifying new potentials for composite technologies in the building and infrastructure market. For the latter, over 25 partners have joined along the entire value chain, from raw materials to OEMs such as producers of facades, panels or window frames. An interesting sub segment is the use of fiber reinforced concrete.



FIGURE 1

Dr. Michael Effing.

AZL is part of the new group for integrative production technology on the campus of RWTH Aachen. It is the largest group with offices for more than 800 people. The group around the AZL is a veritable landscape on its own, where companies are having their own offices and work shoulder to shoulder with the researchers of the universities. Very recently, a branch of this group of integrative production technology was the street scooter company which was acquired by the German post DHL. This branch is now producing approximately 10 000 electrical vehicles per year in Aachen, Germany, for the German post offices, using also affordable lightweight materials.

Together with its partners, AZL can also apply for government-funded projects, for example from the EU or the German government of BMBF or BMWI. Last but not least, an important service is the business development support in the field of new markets and new regions. AZL business partners will be focusing later this year on Eastern Europe, while meeting with industrial partners and government representatives in Poland (Krakow) in October (Fig. 3).

The role of a strong industry organization

Germany is traditionally very strong in the manufacturing sector and has a high percentage of manufacturing in relation to GDP

with 24%. This represents thousands of jobs that should be protected through innovation, complex processes and therefore high barriers for moving away. In comparison, Italy has 15%, Spain 13%, France and UK each 11% of the GDP in the manufacturing sector (values from 2014).

Particularly Germany as a country is highly dominated by the presence of various trade associations. Traditionally, the German industry has been very fragmented with thousands of small and medium-sized enterprises, which have been regrouped and organized in the last decades through industrial research associations to represent their common interests and speak with one voice. This has been particularly successful in the composites industry, which is driven by a lot of break-through innovations.

The role of these trade and industrial associations varies from regional objectives, like companies regrouping around the aerospace industry in the North of Germany or the automotive industry in the south of Germany to overarching goals within an organization aiming to represent common interest on a more global scale. The umbrella organization Composites Germany which is the strongest on the German lightweight market, regroups Germany's four leading trade associations, which are active in the traditional glass fiber industry (AVK), in mechanical engineering industries (VDMA), in the carbon fiber sector (Carbon Composites, CCeV), and in aerospace (CFK Valley). In total, this means over 760 members in industry and research along the entire value chain, raw materials, processors and molders, including OEMs.

As an organization, Composites Germany informs and connects people, businesses, developments and needs regarding composites as a key technology in order to support Germany's economic growth. Advanced lightweight materials like composites bring sustainable and high-quality workplaces to the country. The business is further growing and expanding due to the constant high-quality technological developments and drive for innovation as well as due to the aim for metal replacements through lighter materials.

The government has also recognized the importance of the industry in their "coalition agreement" as glass-fiber and carbon-fiber reinforced composites have both strong growth rates. As per this agreement, with the aim to achieve its climate targets, and for Germany's strategic innovation policy, the government now focuses on the support of the lightweight industry, next to electric mobility and digitization. The government estimates the wind market, building and infrastructure, as well as mechanical engineering to be the main future markets with a strong focus on hybrid lightweight technologies. A big potential is particularly seen also in ceramic composites, in which Germany is world market leader. At federal level, the framework for a broad industrial use has been under construction since 2015, with a specific contact person responsible for lightweight at the Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie), abbreviated BMWi, a cabinet-level ministry of the Federal Republic of Germany. Next steps on this level are the creation of an overview of lightweight related activities in Germany, to create an exchange platform about new and advanced technologies based on company reports, and support the networking between all stakeholders and players on the market. The government has also identified

**FIGURE 2**

Example of a composite building (Image courtesy of AFFAN).

a need for improvement in the area of vocational education and training, and various governmentally-funded projects are ongoing, in which especially the cooperation between various partners in the industry is financially supported.

Thus, one main focus of Composites Germany's work is the lobbying, meaning a close cooperation with representatives of the German government and to support them in their goals to achieve further energy and resource efficiencies, making the country's industry competitive and saving and creating jobs.

The organization Composites Germany stands up to prevent the technology from moving to low-cost countries and supports and promotes innovation and technology, thus, the constant development of energy and resource-efficient processes, and products leading top-class performance applications to their final breakthrough.

The size of the market

Composites are a combination of fibers and resins. The global composites material market (fibers and resins) represents approximately 12 million tons in 2016. With 99% in volume, glass fiber is here determining the market size, versus 1% in volume for the carbon fiber market. In Europe, the overall composites material market for fibers and resins can be estimated with 3 million tons. Glass fiber reinforced thermosets represent 33% (936 000 tons) hereof, glass fiber reinforced thermosets with non-crimp fabrics represent 12% (350 000 tons), glass fiber reinforced thermoplas-

tic with short fibers 48% (1,3 million tons), glass fiber reinforced thermoplastics with long fibers 6% (183 000 tons) and carbon fiber 1% (35 000 tons). The industrial value for finished composite parts is 30.85 billion Euros which is half the size of the lightweight aluminum market. Globally, the glass fiber market grew in 2016 at an annual 5–6% rate, with Europe representing a quarter of this market (3 million tons). The global carbon fiber composites market grew even faster with an annual growth rate of approximately 10%, while the overall tonnage in 2015 was 91,000 tons (fibers and resins). Here, automotive and wind turbines are the fastest growing segments. After a serious economic crisis in 2008, which impacted the European industry dramatically, the composites Industry in Germany and Eastern Europe have benefitted the most. While until 2009, the largest markets were Spain, Portugal and Italy, now Germany is the largest market in Europe with a market share having increased from 12, 9% (2007) to 20, 1% (2016) (Fig. 4).

Summary and outlook

In the last decade, a growing boom was recorded for many industrial markets and applications in the composites industry, as lightweight has so many advantages, like for example, it leads to better fuel efficiencies and less emissions. In 2016, the European Composites market represented 30 billion Euros (worldwide over 125 billion Euros) with a growth rate of 6–8%.

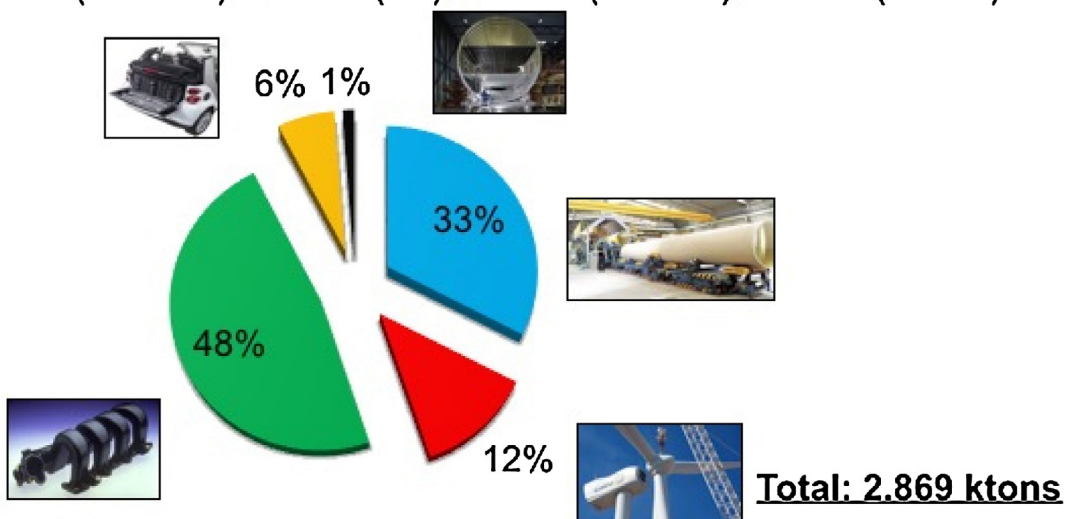


FIGURE 3

Example of a composite building (Image courtesy of AFFAN).

Volume in ktons

■ GFRP(TS) ■ GFRP(TS/NCF) ■ GFRP(TP) ■ GFRP(TP/LFT) ■ CFRP(TS/TP)



- The TP market is the largest segment (54%) and with the fastest growth
- CFRP (TS) represents only 1 % in volume

FIGURE 4

The European Composites market in Volume (2016) (Image courtesy of Dr. Michael Effing, Composites Germany).

Further innovation and cost reduction are needed in order to allow mass-production to stay and further grow in Europe and Germany. There are opportunities to reduce cost, on all levels of the process chain and in the production method like this is the case for the integrative manufacturing. Ways to optimize and smooth processes and intensify the automation of processes are constantly in the focus of the research institutes. One example is the combination of two processes, the thermoforming of a thermoplastic preform and the injection molding to make thermoplastic hybrid components with short and continuous fiber reinforcements. Researchers are currently developing methods for a further cost-reduction of up to 40% by 2020. In glass fiber production, they are working on the improvement of glass properties like tensile strength and

stiffness. In carbon fiber, the focus would be on modified conversion methods with reduced energy consumption as well as on further innovation, cost reduction and efficiency increase of the precursor technology. The expected cost reduction is here up to 20%. In the matrix system, researchers aim to achieve shorter cycle times in the component manufacturing for an additional up to 10% savings. In sum, there are still various opportunities to improve and smooth the production chain in order to assure cost reduction in manufacturing and, in the end, for the user.

This industry needs standards and norms agreed by all parties along the value chain in order to quickly design and engineer new parts. Stable values and reproducible results can be reached and simplify the production.



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Biocomposites: Industry continues to invest in new facilities and chases for GreenPremium

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Composite materials are, as the name suggests, a combination of at least two materials. Materials such as plastics, ceramics or metals are reinforced with different fiber or woven materials. Fiber reinforced plastic composites belong to the group of fiber reinforced composites, and both of these belong to the higher category of composite materials.

Natural fiber reinforced plastics (NFRP), also called “Natural Fibre Composites (NFC)” and “Wood-Plastic Composites (WPC)”, can also be described as biocomposites. This new nomenclature was created as a generic term for materials made completely, or to a significant degree, from renewable organic raw materials (biomass). It refers to biocomposites, which basically consist of NFC and WPC (Figure 1).

The proportion of raw materials of biological origin (excluding bio-based minerals like calcium carbonate, e.g. from shells or precipitated calcium carbonate with CO₂ from combustion) in the final product varies depending on the production and processing techniques that are used. Compression molding allows for a very high proportion of fibers (75% on average in 2012 in Europe). For injection molding, the average fiber share falls significantly (42% on average in 2012 in Europe). In extrusion processes, a fiber share up to 75% is possible, although some producers of WPC claim to use even higher proportions of wood. In 2012 the average European WPC profile extruder used a fiber share of 52%. Using bio-based plastics instead of fossil-based, the biomass content in Biocomposites could be increased by up to 100%. One example of almost 100% bio-based Biocomposites is Green Dot's Terratek Biocomposites produced in Kansas (US) from Braskem's I'm Green Polyethylene (PE), including wood, corn cob, hemp or wheat stalk.

Biocomposites can reduce the greenhouse gas emissions of certain materials by over 50%. Accounting for the carbon storage in the Biocomposites, the reduction can even be 80%. These are very good results compared to other alternative materials, says Michael Carus, the managing director of nova-Institute, Cologne, Germany. Biocomposites have other advantages beyond the environmental benefits, such as product properties,

company image and possibilities for enhanced notice for new products along the total values chain.

Recent research of nova institute uncovered for the first time several backbones behind the GreenPremium. GreenPremium price is the additional price a market actor is willing to pay for the additional emotional performance and strategic performance of the intermediate or end product the buyer expects to get when choosing the bio-based alternative compared to the price for the conventional counterpart with the same technical performance (Figure 2).

nova-Institute has carried out a survey on GreenPremium prices among the industry as well as the end consumers in the frame of the European project BIOFOREVER (www.bioforever.org). The survey was carried out among the following LinkedIn groups related to bio-based plastics: “myBIO Community” (49,000 members), “BioBased Economy” (6000), “Bioplastics” (4000) and “Polymer Chemistry & Polymeric Materials” (20,000), as well as more than 100 personal contacts of nova institute in the bioplastics sector.

Out of the contributors, 69 experts participated in the survey, mainly from companies producing or marketing bio-based plastics, industrial associations and consultants of this market area. All respondents are experts in the field of bio-based plastics, markets and economics. The following results show the answers to the survey which contained only a single question: *GreenPremium for bio-based plastics: How much more are customers willing to pay?*

First results from an international B2B survey of October 2016 disclose that almost 85% of the experts report GreenPremium prices for bio-based plastics. Most of the participants (60%) considered the GreenPremium to range between 10% and 20%,

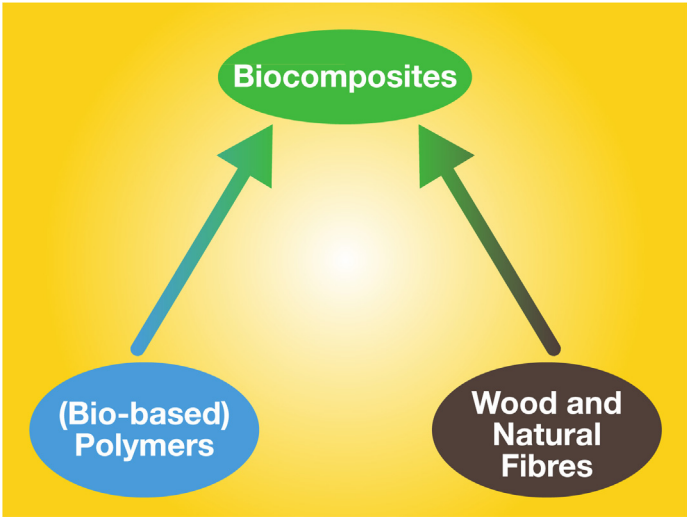


FIGURE 1
Biocomposites.

almost 20% indicated a price premium of 20 up to 40%. About 6% of the respondents see a willingness to pay even more than 50% for bio-based plastics.

The preliminary results of these ongoing surveys show that the main driver for the industry to pay the GreenPremium is the positive green image the product and the company acquires as a result of using bio-based materials. However, it is not only the green image which stands behind the GreenPremium, it is also the innovative image for the product or company.

Injection molding is the market area that shows the most growth in the sector of Biocomposites, starting at a very low market penetration level. Different consumer goods in the market with different natural fibers used to give plastic a sustainable or different look and haptic to standard plastic as an instrument for product differentiation. Different bamboo composites in mugs, e.g. for multiple use “coffee to go” is one of the samples of this kind of phenomenon in the market. These mugs are claimed to be partly biodegradable with a large share of bamboo fibers in it. The product offers a nice smooth haptic, but unfortunately the consumer does not receive much information about the material used.

Metsa group (FI) is building one of the biggest lignocellulosic biorefineries in Europe in Southern Finland Äänekoski. The cooperation with a SME Elastopoli (FI), Saastamala, based on a



FIGURE 3
Aqvacomp composites in LG loudspeakers.

wet mixing technology of never dried cellulosic pulp is a new technology, aims to achieve a homogenous mix of various polymers and realize a reinforcing material that offers several benefits for interior fittings with excellent smooth haptic. This is one of the successful projects to develop new Biocomposites around the new mill of Metsa Group. The never dried cellulose fibers are very efficient produced as a by-product of a state-of-the-art biorefinery and have a carbon footprint of only 320 kg CO₂-eq per tonnes according to the producer Metsä.

Aqvacomp (FI) is the company producing the granules with the unique technology and the know-how of Elastopoli and with the Metsa groups cellulosic pulp. As the next step in the value chain electronics giant LG has started to use these granules called Aqvacomp as a raw material in the manufacturing of loudspeakers, Sound bar SJ 9 (Figure 3), a product group in which acoustic performance is key.

Another area where Aqvacomp Biocomposites offers benefits is musical instruments, as they have been used for the Flaxwood guitar bodies, and also finger boards of violins, as there is a need for the replacement of diminishing ebony wood. Clarinets are being produced from the Aqvacomp granulates for European and Asian markets.

According to ETLA's (FI) calculations, the 1.2 billion € investment in the biorefinery mill will increase the revenue of companies operating in Finland by around 2.4 billion euro at the construction stage, and it will generate value added that will be directly reflected in economic growth in the amount of nearly 1 billion euro during 2015–2018.

Despite the missing support from politics for the industrial use of bio-based materials outside of energy, industry is investing in new Biocomposite facilities. Another example can be found in

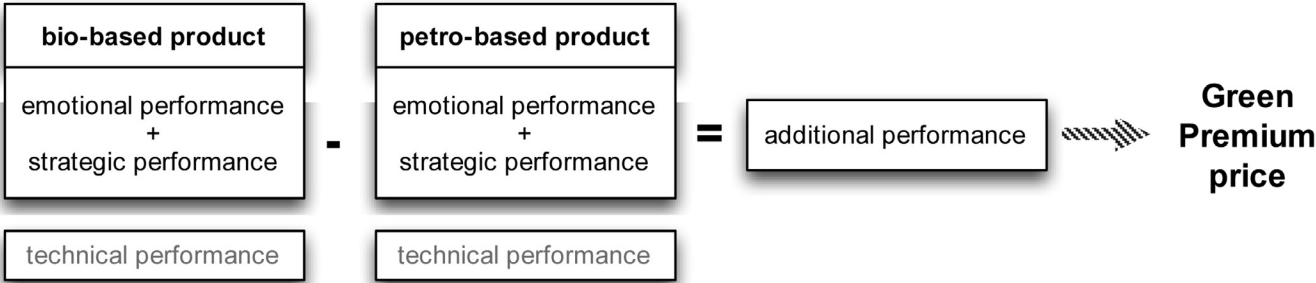


FIGURE 2
GreenPremium price.

South Sweden. Stora Enso, which is a Scandinavian wood-based industry giant, is investing EUR 12 million to build a new production line that will manufacture Biocomposite granules at Hylte Mill. Production is scheduled to begin during the first quarter of 2018. The annual capacity will be approximately 15,000 tonnes per year. Stora Enso has reported the aim to produce components with potential use in Biocomposites including novel modified fibers, and refined natural wood components such as lignin, hemi cellulose and cellulose to be used as natural bio polymers. In the field of Biocomposites Stora Enso has the opportunity to expand in diverse markets and business sectors where plastics have primarily dominated.

Distribution of Biocomposites is not an easy task as the product is not straight forward and combines two different worlds, that of wood and natural fibers with the processing technologies of plastics. One branch of the value chains of the Biocomposites leads from the producer of the Biocomposites over the suppliers of plastic compounds to the users. Several big suppliers of polymers and compounds like Polyone (US) or Biesterfeld (DE) has started to offer additionally to wood and natural fiber reinforced polymers and bio-based polymers.

This could be seen in the K-Show of October 2016, which is the biggest event worldwide of the plastic industry. The portfolios of several suppliers of bio-based polymers, and wood and natural fiber composites compounds were presented, but they were not the focal point of the show. Cellulose fiber reinforced composites were prevalent, as well as different poly-lactic compounds.

Packaging is the leading application for bio-based polymers. In combination with natural fibers, they offer excellent possibilities for eco marketing, especially in biocosmetic cans or packaging for bio-based detergents. These are offered e.g. by German company FKUR. Bio-based polymers do not differ optically from petro-based plastics. Different fibers make different optics by adding accents and can in this way create a certain image of the product.

Danish company Carlsberg is investing in creating beer bottles from wood fibers, which will be thicker but lighter than plastic bottles. The Carlsberg packaging accounts for 45% of their CO₂ emissions; these will be reduced through the new green fiber bottle by 2019.

Following the recent trends of the Biocomposites market, nova-Institute has changed the name of their composite conference from 7th Conference on Wood and Natural Fibre Composites into "Biocomposites Conference Cologne (BCC)", which took place at 6–7 December 2017 in Maternushaus, Cologne.

The seventh "Biocomposites Conference Cologne" will build on successful previous conferences: in 2015 more than 230 participants and 20 exhibitors were represented. It is the largest conference in Europe on bio-based composite materials and it is expanding. More than 230 participants and 30 exhibitors from the area of Biocomposites were present at Cologne.

The topics of the conference included the emerging developments Wood-Plastic Composites from German WPC industry. Anemon Strohmeyer, German Wood-Based Panel Industry (VHI) (DE) reported on the steadily growing production volumes of decking, and the innovations of the German Wood-Plastic Composite Industry.

Biocomposites in Automotive included powerRibs of Bcomp Ltd (CH) (Sophie de Rijk), who use flax grid reinforcements in

automotive large series interiors and race car body parts, and are able to reduce the weight of interior composite parts to as low as 800 g/m². Performance BioFilaments Inc. (Gurminder Minhas) (CA) will showcase benefits of Biocomposites based on Nano-Fibrillated Cellulose Technology in Automotive. A Lightweight solution for wood-based Biocomposites using foaming technology has been developed by VTT Technical Research Centre of Finland Ltd (FI) (Heidi Peltola) for the automotive sector.

Successful injection molding applications of Biocomposites in toys and other consumer goods was presented by the organizer of the conference nova-Institut (DE) (Dr. Asta Partanen). Several injection molding granulates and applications was presented including TENCEL[®] FCP Regenerated cellulose fibers developed by Kompetenzzentrum Holz GmbH (AT) (Dr. Claudia Pretschuh). Dr. Hans Korte Innovationsberatung Holz & Fasern (DE) showed how to reach high throughput technology for rapid compound development.

In the 3D Printing Session Kompetenzzentrum Holz GmbH (AT) (Dr. Andreas Haider) demonstrated the use of Biocomposites in 3D-Fused Layer Modeling. Biocomposites draw in 3D Printing are used recently in large building as is developed by SINTEF Building and Infrastructure (NO) (Nathalie Labonnote).

Also, new raw materials, like new fibers and polymers, for Biocomposites was presented in the Biocomposites Conference Cologne. Fibres Recherche Développement (FRD) (FR) (Anne Le Duc) will draw axes to a better design from plant to agromaterial of bio-based fibers used in thermoplastic composites.

VTT Technical Research Centre of Finland Ltd (FI) (Kirsi Immonen) showcased fiber clay composites from side streams of paper and board industry. Covestro Deutschland AG (DE), Richard Meisenheimer presented new bio-based polyisocyanates for new green lightweight applications. In Situ refiner compounding approach for TMP-fiber thermoplastic composites has been developed by University Hamburg Center of Wood Science and Technology (DE) (Oliver Mertens).

The Biological Materials Group, BIOMIMETICS, City University of Applied Sciences (DE) Prof. Dr.-Ing. Jörg Müssig illustrated how to start New NFC product development and the selection of an appropriate fiber. Dr. Arne Schirp from Fraunhofer-Institute for Wood Research (DE) presented results of improvement of the fire retardancy of wood-plastic composites by wood pretreatment. For all biocomposites experts who could not be present in Cologne: All lectures can be ordered for 150 €: www.bio-based.eu/proceedings.

The Innovation Award "Biocomposite of the Year 2017" was granted at the Biocomposites Conference Cologne to the young, innovative bio-based materials industry for finding suitable applications and markets for bio-based products. The focus of the award is on new developments within these areas, which had been launched in 2017 or will be launched in 2018. The 230 participants of the Biocomposites Conference Cologne (BCC) chose the three winners out of six nominees. GreenBoats (DE): GreenBente24 – a boat from 80% renewable materials was the winner of the award. Usually, mass produced boats are made of fossil-based resins, glass fibres and plastic foam. By contrast, GreenBente24 from GreenBoats (DE) is made for 80% out of renewable materials like flax, cork and bio-based epoxy resin.

**29 July–1 August 2018**

Cairns, Australia
11th Asian-Australasian Conference on Composite Materials
Contact: Cairns Convention Centre
E-mail: accm11conference@gmail.com
www.accm11.org

19–22 August 2018

Lausanne, Switzerland
12th International Conference on Sandwich Structures: ICSS-12
Contact: Composite Construction Laboratory
Tel: +41 (0)21 693 62 63
E-mail: icss12@epfl.ch
icss12.epfl.ch

21–23 August 2018

Detroit, MI, USA
7th Annual Global Automotive Lightweight Materials Summit
Contact: London Business Conferences
Tel: +44 (0) 800 098 8489
Fax: +44 (0) 845 867 8109
E-mail: info@london-business-conferences.co.uk
www.global-automotive-lightweight-materials-detroit.com

5–7 September 2018

Novi, MI, USA
SPE Automotive Composites Conference and Exhibition (ACCE)
Contact: SPE
Tel: +1 203 775 0471
speautomotive.com/acce-conference

5–7 September 2018

Las Vegas, NV, USA
Interdrone 2018
Contact: BZ Media LLC
Tel: +1 (631) 421 4158
E-mail: info@bzmedia.com
www.interdrone.com

10–12 September 2018

Toulouse, France
SpeedNews 19th Annual Aviation Industry Suppliers Conference
Contact: SpeedNews
Tel: +1 424 465 6501
E-mail: jspeed@speednews.com
speednews.com/aviation-industry-suppliers-conference-in-toulouse

10–15 September 2018

Chicago, IL, USA
International Manufacturing Technology Show (IMTS) 2018
Contact: AMT - The Association for Manufacturing Technology
Tel: +1 703 893 2900
Fax: +1 703 893 1151
imts.com

11–13 September 2018

Southampton, United Kingdom
SAMPE Conference
Contact: AMPE Europe Conference Manager
Tel: +31 6 51381263
E-mail: conference@sampe-europe.org
www.sampe-europe.org

11–13 September 2018

Charlotte, NC, USA
UTech North America 2018
Contact: Debbie Hershfield
Tel: +1 330 608 0231
E-mail: dhershfield@crain.com
www.utech-north-america.com

13–15 September 2018

Xiamen, China
7th Annual World Conference on Advanced Materials
Contact: Organizing Committee
Tel: +86 411 84799609 814
Fax: +86 411 84795469
E-mail: elsa@wcam-con.com
www.bitcongress.com/wcam2018

18–20 September 2018

Augsburg, Germany
Experience Composites
Contact: Philip Häußler
Tel: +49 821 2572 106
Fax: +49 821 2572 277
E-mail: philip.haeussler@messeaugsburg.de
www.symposium-composites.com

18–20 September 2018

Cleveland, OH, USA
Extrusion Conference
Contact: Plastics Technology
Tel: +513 527 8800
Fax: +513 527 8801
www.extrusionconference.com

25–27 September 2018

Boston, MA, USA
Aircraft Interiors Americas 2018
Contact: Reed Exhibitions Companies
Tel: +44 20 8271 2134
Fax: +44 20 8910 7823
E-mail: rxinfo@reedexpo.co.uk
www.aircraftinteriorsexpo-us.com

26–27 September 2018

Seattle, WA, USA
ASTM D30 September 2018 Meeting
Contact: ASTM
Tel: +1 610 832 9500
Fax: +1 610 832 9555
service@astm.org
www.astm.org

2–4 October 2018

Tampa, FL, USA
IBEX 2018
Contact: IBEX show director
Tel: +1 716 662 4708
E-mail: anne@ibexshow.com
www.ibexshow.com

3 October 2018

Loughborough, UK
Composites in Sport 2018
Contact: NetComposites Ltd
Tel: +44 (0) 1246 266 246
E-mail: info@netcomposites.com
www.compositesinsport.com

4 October 2018

London, UK
Thermoplastic Composites 2018
Contact: Composites UK
Tel: +44 (0)1442 817502
E-mail: info@compositesuk.co.uk
compositesuk.co.uk

9–11 October 2018

Berlin, Germany
Gocarbon Fibre 2018
Contact: Smithers Rapra
Tel: 01372 802000
E-mail: info@smithersrapra.com
www.gocarbonfibre.com

10–11 October 2018

Munich, Germany
Munich Technology Conference on Additive Manufacturing 2018
Contact: Oerlikon
Tel: +41 58 360 96 96
Fax: +41 58 360 91 96
www.oerlikon.com/mtc-event

15–18 October 2018

Dallas, TX, USA
CAMX 2018
Contact: ACMA
Tel: +1 703 525 0511
E-mail: rosemary@sampe.org
thecamx.org

16–18 October 2018

Hanover, Germany
Foam Expo Europe
Contact: Smarter Shows
Tel: +44 1273 916 301
E-mail: jamie.reid@smartershows.com
www.foam-expo.eu

16–18 October 2018

Hanover, Germany
Sustainable Materials for Transportation Expo
Contact: Deutsche Messe AG
Tel: +44 1273 916 300
E-mail: info@smt-expo.eu
www.smt-expo.eu

16–18 October 2018

Amsterdam, the Netherlands
Helitech International
Contact: Reed Exhibitions
Tel: +44 20 8271 2124
E-mail: harvinder.brar@reedexpo.co.uk
www.helitechinternational.com

25–27 October 2018

Istanbul, Turkey
Eurasian Composites Show
Contact: Artkim Fuarcılık Tic AŞ
Tel: +90 0212 324 00 00
Fax: +90 0212 324 37 57
E-mail: sales@artkim.com.tr
www.eurasiancomposites.com

30–31 October 2018

Dallas, TX, USA
Bremen, Germany
ITHEC 2018
Contact: Messe Bremen
Tel: +49 (0) 421 35 05 347

E-mail: borgmann@messe-bremen.de
www.ithec.de

29 October–1 November 2018

Moscow, Russia
Plastics Industry Show 2018
Contact: ZAO Expocentr
Tel: +7 (495) 255 37 23/33
Fax: +7 (495) 205 80 55
E-mail: centr@expocentr.ru
chemistry-expo.ru/en

31 October 2018

Birmingham, UK
Composites Industry Awards Dinner 2018
Contact: Composites UK
Tel: +44 (0)1442 817502
E-mail: info@compositesuk.co.uk
compositesuk.co.uk

31 October–1 November 2018

Birmingham, UK
Advanced Engineering 2018
Contact: Easyfairs
Tel: 44 (0)20 3196 4350
E-mail: paul.love@easyfairs.com
www.easyfairs.com/advanced-engineering-2017/advanced-engineering-2017/

5–6 November 2018

Stuttgart, Germany
4th International Composites Congress (ICC)
Contact: Composites Germany
Composites Germany
Tel: +49 69/27 10 77 - 0
Fax: +49 69/27 10 77 - 10
E-mail: elmar.witten@composites-germany.org
www.composites-germany.org

6–8 November 2018

Stuttgart, Germany
COMPOSITES EUROPE 2018
Contact: Reed Exhibitions Deutschland GmbH
Tel: +49 211 901 91-0
Fax: +49 211 901-91-123
E-mail: info@composites-europe.de
www.composites-europe.com

14–16 November 2018

Seoul, Republic of Korea
JEC Asia 2018
Contact: Anne-Manuele Hebert, JEC
Tel: +33 1 58 36 43 93
www.jeccomposites.com

21–22 November 2018

Marknesse, The Netherlands
International Symposium on Composites Manufacturing ISCM 2018
Contact: NLR-Netherlands Aerospace Centre
Tel: +31 88 5113113
E-mail: info@nlr.nl
www.nlr.org

4–6 December 2018

San Diego, CA, USA
Carbon Fiber 2018
Contact: CompositesWorld
Tel: +1 858 552 1234
www.compositesworld.com

20–31 January 2019

Amsterdam, Netherlands
Composites in Construction
NetComposites Ltd
Tel: +44 (0)1246 266 246
E-mail: info@netcomposites.com
compositesin.construction