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What V Frames expects from the first recyclable e-bike frame

Three times FIT with PA-CF40

Special reprint

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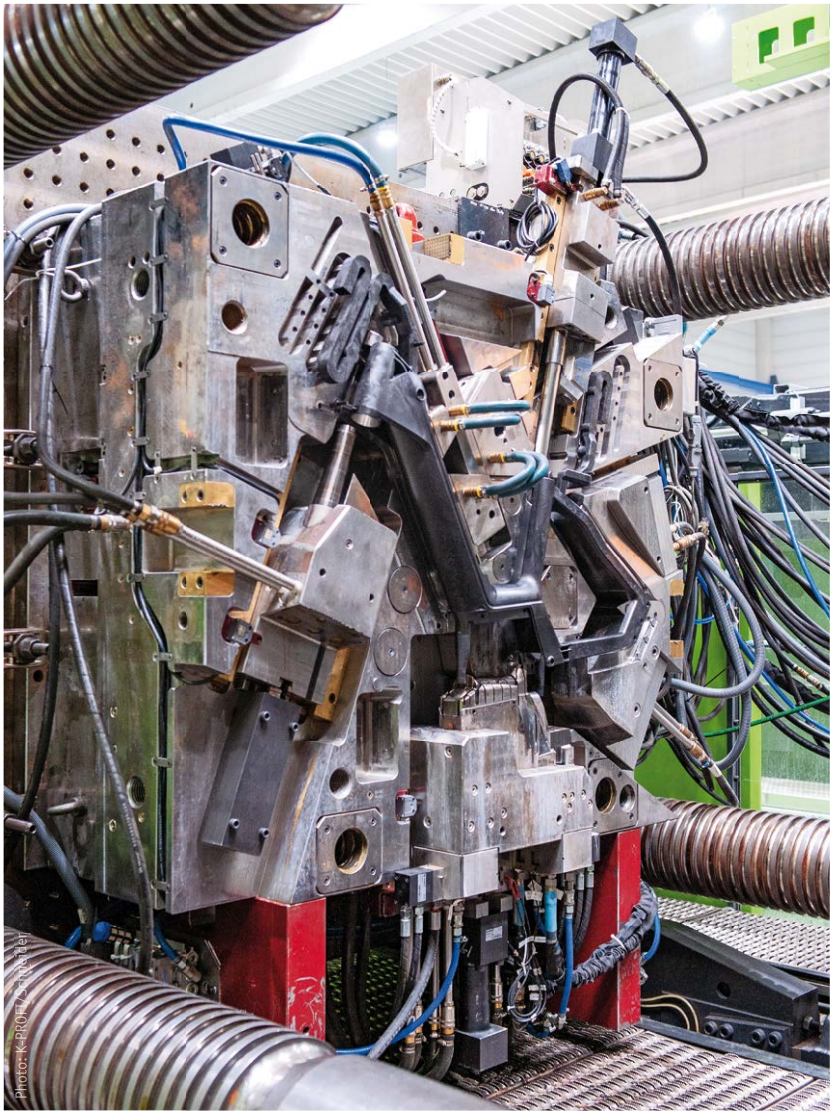


Photos: K-PROFI / Schindler

View into the open fluid injection mould with numerous sliders and the insertion option for the handlebar axle sleeve on a 17,000 kN Engel duo machine.

All-plastic bicycle frames have already put a few inventors on the map. An Austrian-German team has taken on the multifaceted challenges of a low-entry e-bike. On the road until mid-2020 under the Velosione brand, the pioneers from V Frames in Saalfeld, Thuringia, have proven the feasibility of their self-developed „wave frame" made of semi-aromatic PA-CF40 and made it ready for series production using fluid injection technology – with recycling potential and a CO2 advantage over aluminium. Despite the long service life of an e-bike, the makers are already thinking about multiple product life cycles for the plastic of the frame.

Text: Dipl.-Ing. Markus Lüling, Editor-in-chief K-PROFI

V Frames has designed a low-entry bicycle without a top tube, a so-called „wave frame". „An e-bike frame, and a deep-entry frame at that, is one of the most challenging bicycle frames to design in terms of riding characteristics due to the lack of a top tube," notes Dr Umut Cakmak, which is why it was a fundamental decision to manufacture the frame using fluid injection technology (FIT). „Some people have tried to make bicycle frames using injection moulding, but ribbed constructions did not provide the required stiffness. To achieve the primary required torsional stiffness, a closed tube geometry is needed. Our designed deep-entry frame achieves at least the values of a comparable wave frame made of aluminium in all load cases," explains the co-founder and shareholder of V Frames, CEO of the engineering office Plastic Innovation, Ottensheim/Austria, and PostDoc at the Institute of Polymer Product Engineering at the Johannes Kepler University in Linz.

The common ISO test standards for bicycles are focused on fatigue and not on stiffness or – even more important for the development process – on driving characteristics. „We used experimental investigations to determine the links between mechanical characteristic values and properties of driving dynamics," explains Dr Umut Cakmak. „The values from the defined load cases served us as a benchmark because we also had to achieve the lateral stiffness values, which are not specified in the norms and standards, in order to also create the connections from design and manufacturing to driving dynamics. For this, we came up with our own standards and load cases, which will help us considerably in future projects regarding component design."

Intensive simulation and structural analysis

„Achieving our goal of implementing a deep-entry frame using injection moulding was anything but a no-brainer," says Christian Wolfsberger, co-partner of the engineering firm for product development Plastic Innovation and Business Development Manager Lightweight Composites at the injection moulding machine manufacturer Engel: „At Plastic Innovation, we worked out the idea down to the last detail. We went straight for a deep entry model because it was clear to us that if we managed to successfully implement this frame model, then we could also realise any other model. It all started when we came up with a procedural concept for manufacturing. In the concept phase, we had to make sure that the product with several fluid volume flows was also feasible in terms of process technology. Then we worked our way up step by step with regard to the requirements for the structural properties, stretched real aluminium frames on the test bench and measured the deformation values when force was applied. Thus, we had a benchmark. In intensive cooperation with Coleo Design, Cologne, some sketches and then a CAD model were created. During the design phase, special attention was paid to the technical feasibility and the subsequent process engineering implementation, also because at that time we were not aware of any other component in which three fluid volume flows push the plastic core out of the component at the same time. The volume flows must be separately controllable and must not influence each other. We are talking here about large volumes that are pressed out of the component. To ensure that the frames also have the desired quality and that we don't go blindly into a mould, we have designed and optimised the component according to the load by means of intensive filling and structure simulations."

For the filling simulations, the engineers rely on Moldex-3D. „It is very important that the fluid injection with the residual wall thickness and fibre alignment to be achieved can also be realistically mapped in the filling simulation. Both the cavity formation and the fibre alignment are crucial for the subsequent structure simulation," says Dr Umut Cakmak. The analyses of the filling simulation include the injection process, the holding pressure and cooling phases. Critical weld lines, air pockets and defects in the fluid injection phase can be identified. These faults are eliminated by optimising the frame design, then simulated and analysed again until the bicycle frame is process-optimised. „We work with the designers from a very early stage in the design process and think about the plastic-appropriate design and the associated tooling technology right from the design stage. We had to design according to the material and the process in order to exploit the full potential of the material. The mechanical design includes the load cases of the standards as well as axial and lateral static loads, which provide conclusions about the driving dynamic performance. The loads of these requirement profiles were mapped and optimised in several structural analysis loops. Validation experiments were conducted concurrently to improve the material models of the simulations. From the design freeze onwards, we have to ensure to the customer that the product has exactly the properties that meet the requirements."

The e-bike with the Wave frame from V Frames in use.

High-performance material with recycled carbon fibres

During the development phase, the team tested several matrix materials – each with different reinforcing fibres in varying degrees of filling. Together with the compounder Akro-Plastic, the experts determined that a semi-aromatic polyamide with 40 wt.% carbon fibre reinforcement (CF) was optimal. Michael Rieck, Business

Dr Umut Cakmak, CEO at Plastic Innovation as well as PostDoc at Johannes Kepler University Linz, sees the wave frame without top tube as the most difficult geometry possible for bicycle frames.

Development Manager at Akro-Plastic: „Compared to a high reinforcement with 60 wt.% glass fibre in the polyamide, carbon fibres save 20 % in density and bring 70 % more stiffness."

Akro-Plastic already relies on a reclaimed carbon fibre in the Akroloy ICF product range used here to produce the base material. „We reprocess a continuous fibre product that has not previously come into contact with resin or thermoplastic, thus deriving the carbon fibre for our compound," explains Michael Rieck. „Although CF-reinforced material is more demanding to process, it is well suited for fluid injection technology," he reports, „we have been working very intensively on FIT. One of our pilot plants in Niederzissen can handle these applications. This made continuous material adjustments possible on the one hand, and targeted optimisations for the FIT process on the other."

Industrial implementation at injection moulding processor Isoco

The technical realisation takes place at Isoco Plastics Technology in Saalfeld-Schmiedefeld, which is a shareholder of the bicycle frame manufacturer V Frames. Managing Director Michael Müller took over Isoco from insolvency in 2013. Today, the company produces small load carriers, returnable containers and pallets made of recycled polyolefins on the one hand, and other injection moulded parts and moulded parts made of reinforced plastics on the other hand in two plants at the same location. The injection moulding machinery includes clamping forces between 400 and 23,000 kN.

Michael Müller is managing director of Isoco and V Frames.

„Highly filled fibre-reinforced thermoplastics are something new for us, but then again they are not. Here at the site, 700 employees used to produce hand laminates for caravans," Michael Müller looks back on the history since 1960. „We come from injection moulding, and we are competing not to make an old standard in injection moulding, but to pursue new projects again and again. We started with the boxes. These products with high recycled content were a real challenge, but we started very successfully with them. Today we process 10,000 tonnes of polyolefin recyclate per year into boxes and pallets."

For the production of bicycle frames, Isoco has invested in a large Engel duo injection moulding machine with a clamping force of 17,000 kN and a high-quality plasticising screw for processing highly reinforced materials. In addition, for smaller bicycle frames there is an exchangeable cylinder so that the shot weights can be reduced. Add-on parts for the frames, such as the battery compartment cover, are produced in another plant in Erfurt.

Triple FIT application on the PA-CF40

A total of three channels are placed as permanent cavities in the closed frame – on the one hand under the battery compartment in the down tube, and on the other hand in the two brackets that form the seat and chain stays in the rear triangle. For this purpose, after filling the mould and an initial cooling of the edge layer, fluid is forced into the interior of the moulded part at three points via injectors, while

core pulls open so-called secondary cavities at the fluid channel end to accommodate the still plastic core. The fluid volume flows are controlled separately from each other. At the end of the fluid process, the fluid pressure inside the component is briefly maintained, quasi as holding pressure in the entire cavity interior. The process is therefore very low in shrinkage and distortion, and the components do not have any sink marks.

The finished plastic bicycle frame weighs 3.2 kg. Of the almost 4.5 kg shot weight, the three fluid volume flows displace 1.2 kg into the secondary cavity. As an alternative to the so-called blow-out process into a secondary cavity, the so-called mass push-back process is also being examined for future projects. In this process variation, the plastic core is pressed back through the hot runner into the screw antechamber of the injection unit instead of into a secondary cavity. The material that is pushed out can then be injected again during the next shot. In the eyes of those in charge, extensive know-how in the entire process chain of filling and structure simulation, design, mould construction, process engineering and material behaviour is decisive for the good result.

QA through close tolerance band monitoring

Particularly important is the reproducibility of the process with identical properties from moulded part to moulded part. To this end, those in charge are currently defining the process window more narrowly. „Because we have optimised the process and therefore many parameters, we can produce the frame in 100 seconds cycle time with constant quality."

A 100 % inspection of all moulded parts produced has proven to be unnecessary. Dr Umut Cakmak: „We set up a DoE (Design of Experiment) with all relevant parameters and determined correlations of machine parameters to component properties." Christian Wolfsberger: „This means that it is sufficient to have the process parameters monitored in the machine control system for tolerance band transgressions. In the sampling, we determine how tightly we set the quality parameters to be sure." Of course, V Frames relies on complete traceability through parameter-based documentation. „We are now going into series production and setting up a small testing laboratory," Michael Müller reports, „all


Photo: K-PROFI/Schneider

Christian Wolfsberger co-developed the Wave frame for e-bikes and is Business Development Manager Lightweight Composites at Engel.

Photo: K-PROFI/Schneider

This X1 carbon frame for Norwegian brand Buddy Electric is also to be produced in around 100 seconds cycle time.

Freshly demoulded frames, still with the secondary cavities filled by the fluid injection technique.

in all, we will determine which mechanical tests are to be carried out on each part and how many. Currently, we are producing 500 frames each for two months, then 3,000 per month. The theoretical capacity is 1 million pieces per year on our machine."

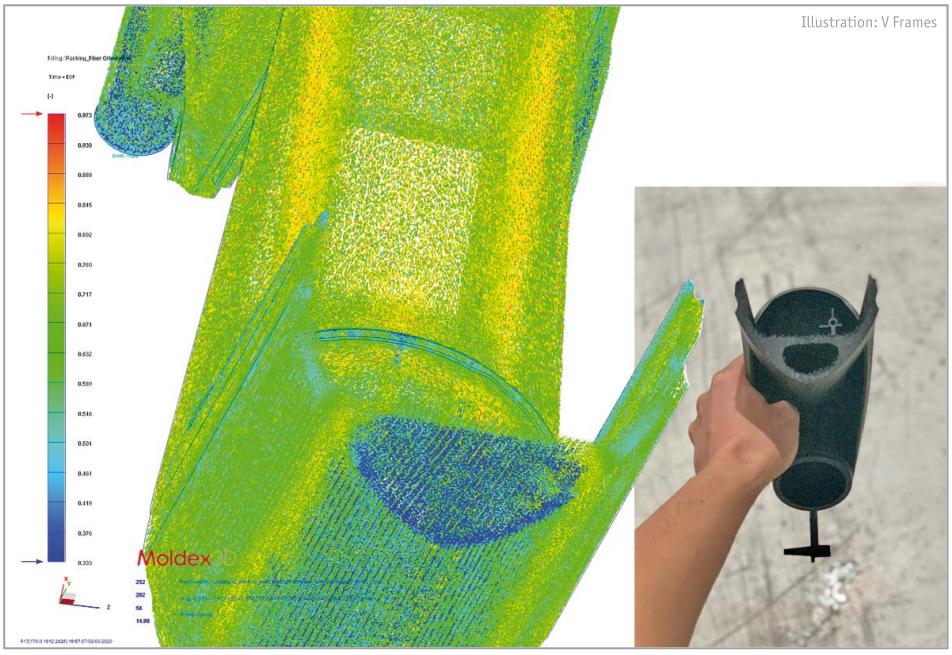
Strong support from the machine manufacturer

As an injection moulding machine manufacturer, Engel has accompanied and supported the project for years. Christopher Vitz, President Europe Central at Engel: „V Frames is a project where an innovative idea coupled with the team's ability to implement and the economic efficiency of the concept have resulted in a totally innovative product." Christopher Vitz, also a member of the advisory board of the Open Hybrid Lab Factory in Wolfsburg, is full of respect for the achievement: „Anyone who consistently commits to an idea and tackles an innovative manufacturing process has to tackle a very broad field. The people at V Frames have brought in university know-how, engaged calculation expertise and implemented everything brilliantly. Nevertheless, we are only at the beginning of a large potential business area that can really make a difference in a user industry. A good product with a good ecological balance, with recycling potential and with the potential to do something positive for society. We'll be hearing a lot about this in the next few years," he says with conviction – and makes a statement for his employer: „If we at Engel have the chance to get involved in such projects, we're happy to take it."

The large injection moulding machines at Isoco mainly produce load carriers, folding boxes and plastic pallets. A 17,000 kN model also produces bicycle frames.

Plastic frames for just-in-time assembly

The final assembly of high-quality e-bikes mainly takes place in Germany and the Netherlands, which is why just-in-time production is definitely possible in Saalfeld, explains Michael Müller. „From Asia, we always have the sea route in between." Michael Müller describes the investment costs for tools as a major barrier to market entry. „We only achieve amortisation through the production of frames. Our concept is interesting for customers who are interested in large quantities of about 6,000 or more. A single tool can produce around 300,000 frames per year. But hardly any individual bicycle manufacturer needs such quantities. Nevertheless, we could already serve a very large market through this one machine."



The filling simulations with Moldex-3D realistically depicted the achievable residual wall thicknesses and fibre alignments during fluid injection.

Several projects and geometries in the pipeline

The Isoco Bikes division will start selling the first commercially available production bike with a Wave frame in the autumn. V Frames, meanwhile, has other bike frames in development for various OEMs. „Concrete projects include a children's bike and several other models. Currently, seven tools are in the design stage," Michael Müller reported. For example, Norway's Buddy Electric is among the first to start selling e-bikes with carbon composite injection moulded frames. The proprietary


Christopher Vitz, President Europe Central at Engel, praises the team effort at V Frames.

Photo: K-PROFI/Schneider


The residual wall thickness and the fibre orientation are essential quality parameters and criteria for compliance with the load specifications determined in the structural analysis.

Photo: K-PROFI/Schneider

design of the frame „Made in Germany“ comes from Eker Design and Buddy Electric. „Buddy Electric is not our first customer, we have other orders and moulds in development and production, but these are still subject to various NDAs. In the coming months we will announce more OEM frames,“ says Michael Müller. Buddy Electric from Norway has more than 20 years of experience with electric vehicles and had already developed a first e-bike in 1993. It was only in 2017 that Buddy successfully resumed the product and has since advanced to become one of the largest e-bike manufacturers in Norway. The Buddy sX1 should be available in the first quarter of 2022.

Sooner or later, Michael Müller wants to expand the clamping force range at Isoco to 35,000 kN – not only for the growing business with large containers and large pallets but also to be able to injection mould plastic frames for cargo bikes, for example.

Multiple product life cycles in sight

Back to the current model: how does V Frames intend to organise an orderly and quantitatively satisfactory return of frames for a consumer product that is used for a longer period of time? Michael Müller: „We assume that the buyer of an e-bike registers with the manufacturer to document his warranty claims. This keeps a relationship from the manufacturer to the user.“ At the end of the life cycle, the frame of the e-bike should become the frame of a CityBike, the frame of the CityBike a few years later should become the frame of a children's bike, and the frame of the children's bike should then become the frame of a running bike. „This way we can create multiple product life cycles over a very long time.“

Top left: As Area Sales Manager at Engel, Matthias Hölscher looks after customers in Thuringia, including Isoco and V Frames.

Top right: As Engel's service technician, Florian Rammer accompanies current trials by V Frames on fluid injection technology with recyclates.

Below: Michael Rieck, Business Development Manager at Akro-Plastic, is convinced of the potential of CF compounds for the bicycle industry.

The very day after K-PROFI's summer visit, V Frames launched a new round of attempts to process production recyclate from frame production into new frames – and not just with admixtures, but with 100 % recyclate.

www.v-frames.com
www.plasticinnovation.at
www.isocobikes.com
www.akro-plastic.com
www.engelglobal.com