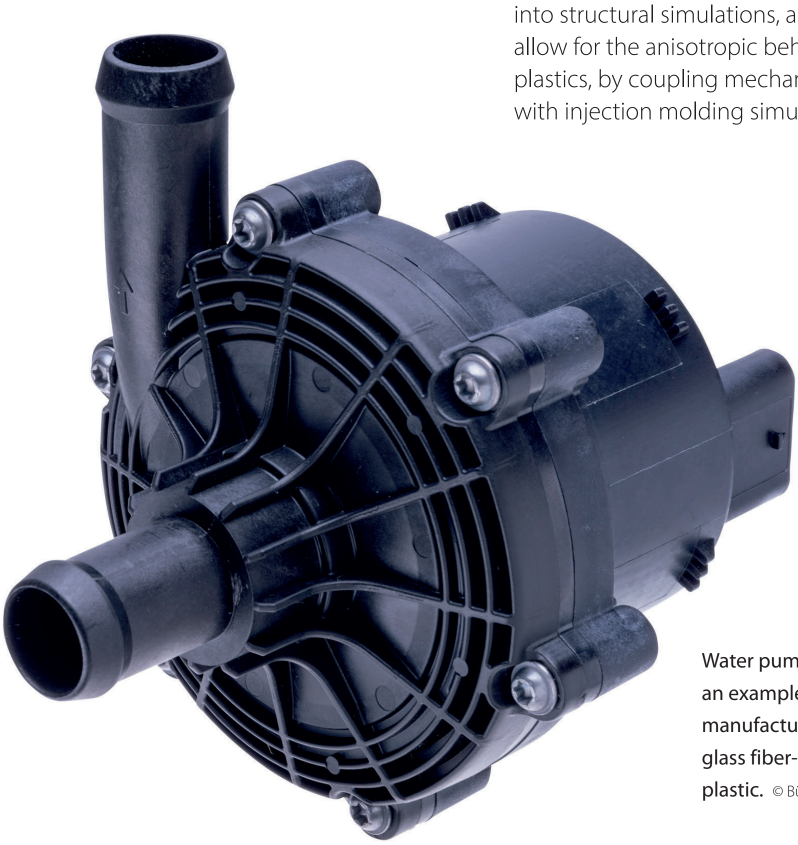
Factoring Fiber Orientation into Structural Simulations

Anisotropic Simulation of Short Fiber-Reinforced Plastics

Short fiber-reinforced plastics are used for many technically demanding applications. For efficient development processes and high product quality, their anisotropic material properties must be factored into the design cycle. A simple approach often taken is to reduce the material stiffness. However, a more accurate approach is to consider the effective fiber orientation. This article discusses the pros and cons of both approaches.

Plastics intended for use as construction materials possess material-specific advantages that open up a wide range of applications to engineers. They boast a high degree of design freedom and very good processing properties that facilitate even large production runs of complex parts. Often, their properties are significantly enhanced by the incorporation of fillers and reinforcing materials, such as glass fibers. The added fibers confer anisotropic, i.e. direction-dependent, properties on the materials during part production. Bühler Motor GmbH came to realize that, if achieving a lasting increase were to be achieved in development and product quality, it wanted to be able to use the finite element method (FEM) to incorporate this anisotropy as realistically as possible into simulations.

In the past, the material properties of plastics were deemed to be isotropic, i.e. the same in all directions. As fiber-reinforced plastics generally have anisotropic properties, isotropic simulations therefore failed to adequately predict part behavior in some applications. However, it is possible to factor fiber orientation into structural simulations, and thus to allow for the anisotropic behavior of plastics, by coupling mechanical analysis with injection molding simulation.



Water pump bFlow C as an example of a part manufactured with short glass fiber-reinforced plastic. © Bühler Motor

Realistic Mapping of Local Stiffness

The SFRC workflow (short fiber-reinforced composites) is a simulation tool in Ansys Workbench that accounts for the material anisotropy (**Fig. 1**). It has been a component of the Ansys Mechanical Enterprise license since the release of 2021 R1 and was tested and evaluated at Bühler Motor GmbH as part of a bachelor thesis [1]. Ansys provided the necessary software and license while Cadfem GmbH provided support in the form of know-how.

Ansys Material Designer makes it possible to create a material model that is dependent on local fiber orientation. It employs homogenization techniques to determine the effective orthotropic, linear-elastic properties of the composite material from the (isotropic) linear-elastic properties of the matrix and fiber material. The elasto-plastic material behavior is determined by calibration against experimentally determined 0° and 90° stress-strain curves. Once a material card has been generated, it can be used in any simulation project.

The Ansys Injection Molding Data object is used to import fiber orientations (as well as local fiber volume content, initial stresses and weld line information) determined in injection molding simulations into Ansys Workbench. Ansys Mechanical maps this data onto the mesh used in the structural simulation (**Fig. 2**). This is then used with the orthotropic material generated in Ansys Material Designer to realistically reproduce the local stiffnesses in the part.

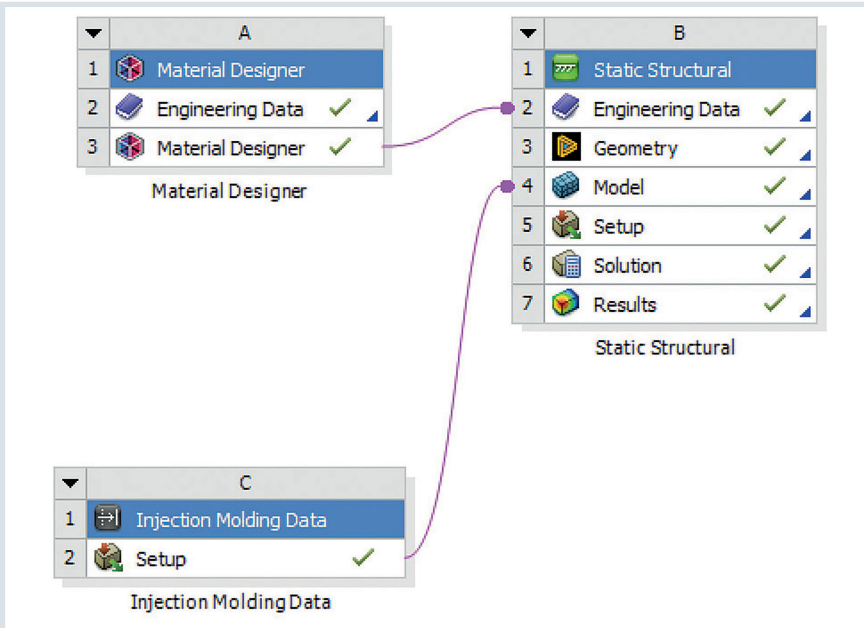


Fig. 1. Typical workflow for simulating short fiber-reinforced materials in Ansys Workbench. (A) Ansys Material Designer: generating an anisotropic material model, (C) Injection Molding Data: importing fiber orientations, (B) Static structural: definition of the FE model. © Bühler Motor

The workflow, along with application examples, is described in the technical literature [2]. A detailed description can be found under Material Designer User's Guide in Ansys Help as well as in the Short Fiber Composites Guide [3].

Comparison of Isotropic and Anisotropic Simulations

The aim of this work was to establish the amount of added value generated by anisotropic simulation, compared to the existing system of isotropic simulation. This included assessing whether factoring fiber orientation into short fiber-reinforced plastics would yield a realistic representation of the stiffness of the plastic in the structural simulation. It also entailed establishing whether considering fiber orientation makes economic sense or whether it is sufficient to apply a general reduction factor as a means of factoring the material properties into an isotropic simulation.

The first step was to obtain the results of a tensile test (adapted from DIN EN ISO 527 [4]) carried out on a partially aromatic polyamide with a 40 % glass-fiber content (PPA-GF40; manufacturer: EMS-Chemie AG) in order that the simulation could be compared with experimentally determined stress-strain behavior.

Ansys Mechanical was used to numerically map the tensile test, factoring in the »

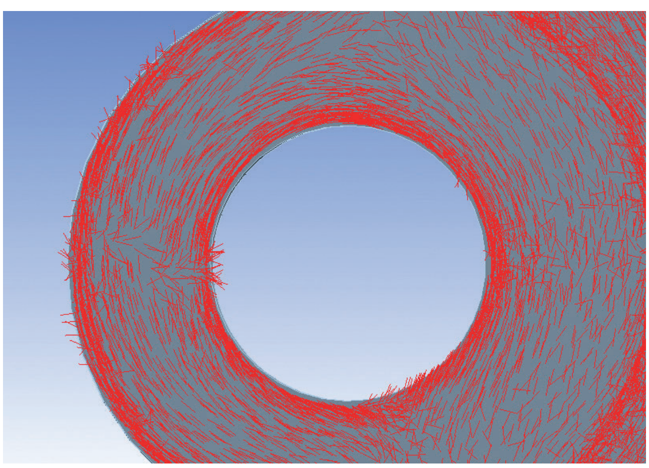


Fig. 2. Main fiber orientations mapped in Ansys Mechanical from the injection molding simulation at a through-hole on the pump head. © Bühler Motor

Info

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Practical Benefits

The following advantages of anisotropic simulation were identified:

- Stress-oriented simulations
- Realistic prediction of part behavior
- Savings on development and test cycles
- Fewer part tests
- Optimization of material usage

References & Digital Version

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German Version

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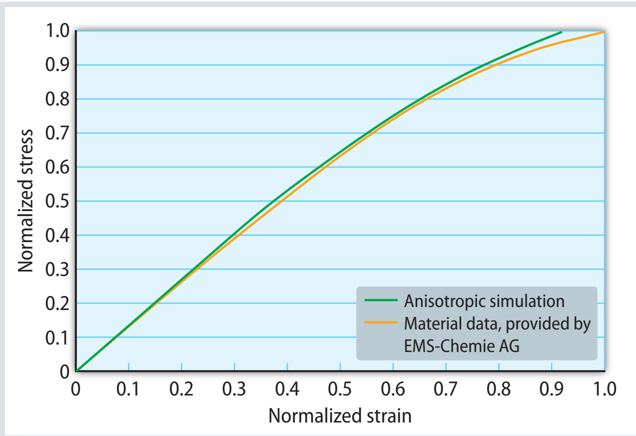

Fig. 3. Comparison of the experimentally determined stress-strain curve and the simulated values for a tensile test carried out according to DIN EN ISO 527 (material: PPA-GF40). Source: Bühler Motor; graphic: © Hanser

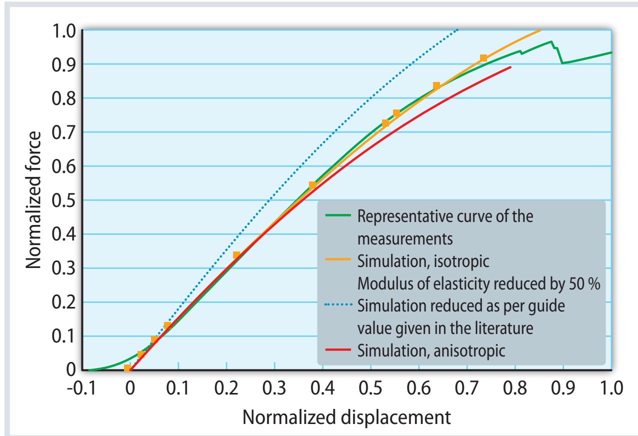

Fig. 4. Comparison of different part simulations with values determined experimentally in a part test (normalized values). Source: Bühler Motor; graphic: © Hanser

local fiber orientations (determined with the aid of Autodesk Moldflow Insight 2019). The experimentally and virtually determined stress-strain curves were then compared (**Fig. 3**). This revealed that the SFRC workflow is good at reproducing the experimentally determined stress-strain curves, with a maximum deviation of -8 %.

The second step was to validate a part. The part in question was a type bFlow C water-pump head (**Title figure**) from Bühler Motor. This head is made from a short fiber-reinforced material. The test itself consists in applying a compressive force to the pump head and measuring the resulting deformation.

Deviations within the Expected Range

Ansys Material Designer was used to numerically determine the properties of the short fiber-reinforced material used in the part. Subsequent simulation of the part test yielded a good approximation of the measured part behavior (**Fig. 4**), with the maximum strain deviation coming in at -9 %. This is within the range of deviations that might be expected in light of the manufacturing process for the parts and the scatter of the individual experimentally determined curves.

By way of an alternative modeling variant, a simulation was performed on isotropic material (without considering local fiber orientations). To this end, the material's modulus of elasticity, which was determined by means of a tensile test performed on a short fiber-reinforced specimen (as per DIN EN ISO 527), was reduced by 50 %. This allowed even better agreement to be achieved, compared with the test results for the part. Admittedly, that was possible only because the reduction factor was determined over several iterations in a part test. A reduction factor of 0.6, commonly cited in the literature [5], yielded much worse results (**Fig. 4**).

Use of the Anisotropic Simulation in Product Development

In the course of the work, the computational expense of the simulation, factoring in the anisotropic material behavior, was found to increase. As such computation is heavily geometry-dependent, it is not possible to generalize about the additional expense.

Wherever it is necessary to factor the material behavior of short fiber-reinforced into an isotropic simulation, it is commonplace to employ reduction factors for the modulus of elasticity. However, the reduction factors recommended in the literature can only be used to obtain rough estimates. More accurate reduction factors specific to the load case and part require time-consuming and cost-intensive part tests.

These reduction factors are not easily transferable to other parts or load cases. Contrast this effort, which has to be repeated for each part and each load case, with the generation of the material card needed in the case of an anisotropic simulation. This working step only has to be performed once for each material in use. Given a properly maintained material database, this effort will reduce over the long term.

Isotropic simulations do not map areas of local differences in stiffness that result from the fiber orientation. It is therefore impossible to correctly identify local stresses in the parts. Contrast this with anisotropic simulations, where it is possible to more accurately characterize the influence of weak points, such as the stiffness of weld lines. This facilitates targeted plastic part design and so can shorten development and testing times. Simultaneously, anisotropic simulations permit load-oriented part optimization, which can reduce the amount of material used.

Conclusion

An isotropic simulation based on a reduction factor for the modulus of elasticity stated in the literature should be sufficient to estimate the behavior of a part still under development. Factoring the fiber orientation into the structural simulation as early as possible in the development process permits to identify and avoid potential weak points early in the design cycle. Critical areas can then be mitigated and improved at low cost. The outcome is fewer prototypes and reduced testing.

In summary, it can be said that anisotropic simulation offers many advantages over its isotropic counterpart. However, whether this type of simulation brings sufficient added value for given products and at a particular stage is a decision that must be taken on a case-by-case basis. ■