Kurzdarstellung

Energieeffizientere Konstruktionen insbesondere in der Automobilindustrie und bei deren Zulieferern erfordern die Substitution schwerer Bauteile aus Stahl und anderen metallischen Werkstoffen durch entsprechende Leichtbauvarianten aus Kunst- bzw. Verbundwerkstoffen. Dieser Trend setzt sich nach der erfolgreichen Einführung von Kunststoffbauteilen im Innenraum von Automobilen auch vermehrt bei sicherheitsrelevanten Konstruktionen z.B. im Motorraum durch. Um die hohen Anforderungen an die mechanischen Eigenschaften der verwendeten Materialien erfüllen zu können, werden überwiegend Faserverbundwerkstoffe eingesetzt. Da im Rahmen der Bauteilentwicklung der Einsatz der Finite-Elemente-Methode (FEM) mittlerweile zum Stand der Technik gehört, müssen auch für Faserverbundwerkstoffe die entsprechenden Materialmodelle auf ihre Anwendbarkeit hin überprüft und gegebenenfalls weiter oder neu entwickelt werden.

In dieser Arbeit wird ein Versuchs- und Auswertekonzept zur Bestimmung der mechanischen Materialkennwerte von langglasfaserverstärktem Polypropylen (PP-LGF) vorgestellt und validiert. Es wird orthotrop visko-elasto-plastisches Materialverhalten des Verbundes angenommen. Zur Ermittlung der Datensätze für die FE-Simulation werden Zug- und Schubversuche bei fünf unterschiedlichen Abzugsgeschwindigkeiten von quasistatisch bis 10 m/s durchgeführt. Dabei werden mit Hilfe der Grauwertkorrelationsanalyse berührungslos Dehnungsfelder auf der Oberfläche der Probekörper erfasst und später mit Kraft-Zeit-Daten zu Spannungs-Dehnungs-Kurven verrechnet. Das orthotrope Materialverhalten von PP-LGF wird berücksichtigt, indem sowohl Zugversuche an Probekörpern mit vorwiegend in Zugrichtung als auch an solchen mit überwiegend quer dazu orientierten Fasern ausgewertet werden.

Die Dehnratenabhängigkeit des Materials wird über einen visko-elasto-plastischen Ansatz in 1D getrennt für zwei Zugbelastungsrichtungen mathematisch beschrieben und die Parameter über einen Least-Square-Fit unter Verwendung des Levenberg-Marquardt-Verfahrens bestimmt. Im Rahmen eines Vergleichs experimentell ermittelter Verschiebungs- und Dehnungsfelder einer gelochten Zugprobe mit den Ergebnissen einer korrespondierenden FE-Simulation wird ein orthotrop elasto-plastischer Simulationsansatz in 3D validiert. Dabei wird eine Formulierung nach HILL für orthotropes Fließen berücksichtigt. Am Ende der Arbeit wird gezeigt, inwieweit das erfolgreich validierte Modell auf eine komplexere Bauteilgeometrie übertragen werden kann. Es wird deutlich, dass bei sehr komplexen Geometrien die Qualität der Simulationsergebnisse nicht nur vom verwendeten Materialmodell und der Güte der Materialparameter abhängt, sondern zunehmend von der Qualität einer der FEM vorgeschalteten Füllanalyse.

Abstract

The scarcity of raw materials such as oil and natural gas has led the necessity to design more and more energy-efficient constructions. This applies particularly to the automotive industry and its component suppliers. There are two possibilities to meet this obligation. On the one hand, one can develop new forms of drive concepts, e.g. hybrid or electric motors. On the other hand, the reduction of weight can significantly diminish the consumption of fuel. Especially in the aerospace industry every gram less counts. To put this requirement into action traditional materials, e.g. steel and cast iron, are replaced by new lightweight materials. This can be miscellaneous light alloys or one of several fibre reinforced plastics. After the production of plastic devices such as display panels in cars, more and more security-relevant plastic devices appeared.

This report deals with one important material within the group of glass fibre reinforced thermoplastics i.e. long-glass-fibre reinforced polypropylene. Polypropylene with approximately 14% of the worldwide usage of plastics is very cheap and can support companies in cost-saving. This aspect becomes more and more important considering the expansion of global business competition, especially in the automotive industry. With approximately 50%, glass-fibre reinforced polypropylene is the dominant material in the group of glass fibre reinforced thermoplastics. To counteract the demand of shorter development times in the design process the automotive industry and its suppliers count on simulation tools such as the finite-element (FE)-simulation. For this reason the quality of the mathematical material models has to be improved and its parameters have to be identified. After choosing a suitable material model and identifying the corresponding parameters, a verification of both has to follow to assure their reliability. This is typically carried out by comparing measurement with simulation data at distinctive points of the considered geometry. With advanced performance of computer hardware and measurement systems it is possible to measure specimens and more complex geometries at high strain rates by means of high speed cameras and to conduct FE-Simulations in a justifiable time with sufficient accuracy.

Thus the following chapter firstly discusses the basics of continuum mechanics with its well-established mathematical formulations for anisotropic elasticity, plasticity and viscoelasticity and the corresponding rheological models. In chapter three the properties of the matrix material polypropylene are presented with more precise consideration of the strength and failure of the composite material under tensile load depending on the fibre length and volume. Thereafter, the geometry and dimensions of the specimens for tensile and shear tests are presented, together with a test sample which is used as an example for the design of automotive structures via coactions of measuring and simulation techniques. Chapter four deals with the state of the art in high speed testing, the experimental setup and its mode of operation as well as the explanation of different kinds of evaluation software which is used in this work.

Here, the main focus is aimed at the determination and interpretation of displacement and strain fields with the grey scale method. The following paragraph describes different initial examinations of specimens and the test sample. In this context, exposures of fracture surfaces and polished micrograph sections were examined by means of optical and scanning electron microscopy. In this way discontinuities and cracks caused by the injection moulding process are detected. The quality of the specimens and the test sample and their suitability for systematic material testing are finally evaluated by means of thermoelastic stress analysis and a laser extensometer. With these systems a direct optical strain measurement can be accomplished to screen the homogeneity of specimens and parts.

In chapter six an approach for an experimental method is presented for measuring displacement fields of the surface of specimens of long-glass-fibre reinforced polypropylene at high strain rate. A strategy is introduced for reasonable data evaluation to characterise stress strain behaviour under tensile and shear load. Specimens of long-glass-fibre polypropylene with a fibre volume content of 30% and 40% respectively, are tested and analysed. Anisotropy of the material is considered by testing specimens with fibres oriented either in the direction of the tensile load or perpendicular to it. The resulting stress strain curves for the two main directions are used as basis for identifying material properties for an orthotropic constitutive law. Hence the elastic parameters that are collected from stress strain curves are the axial modulus in fibre direction and perpendicular to it, the shear modulus in the fibre plane and the matrix plane and finally the lateral contraction in fibre direction, at right angle to it and in the matrix plane. After having collected the parameters for elasticity, the HILL-criterion is utilised to describe orthotropic plasticity. The different stresses at the yielding points related to the designated directions are used to compute the parameters of the HILL-criterion. Finally, in order to describe the strain-rate dependent behaviour of the material, a one dimensional rheological model with four relaxation terms is utilized to represent the set of curves resulting from tests of specimens at five different strain rates. The viscoelastic parameters are identified by means of a least square approach using the Levenberg-Marquardt algorithm.

In chapter eight, the elastic-plastic orthotropic material model is verified for low strain rates. A specimen with a hole in its middle is exposed to a tensile load until break and simultaneously measured by means of a CCD-camera to obtain the two-dimensional displacement field on its surface. Comparison of the experimental displacements with the displacements of a finite-element model at the same points shows the quality of the material model and its parameters. Finally, in chapter nine, the results of a filling simulation of the test sample is shown and again a comparison of measured and simulated data is presented. This we describe the potential and the limits of current filling-simulation-software in conjunction with a popular finite-element-tool like ABAQUS. To conclude appropriate mathematical characterisation and reliable parameters of long-glass-fibre reinforced polypropylene require stringent experimental and theoretical characterisation. Complete specification of such a complex material is still very time-consuming and prone to mistakes during the whole sequence of operations. For this reason it is very important to improve the reliability of every single step in product engineering. Hence the performance of a mathematical material model is not only dependent on its formulation but also and particularly on the quality of its material parameters whether they are determined directly from material tests or by means of special optimization software. The best optimization tools can only optimize material parameters reliably if the underlying experimental data is just as reliable.