Lifecycle Testing. The trend towards combining ever more complex functions in one plastic part is presenting new challenges for specimen testing. In addition to the test demands achieved for the applicability, the definition of the test parameters in close cooperation with engineering, simulation, component validation and materials experts contributes in particular to precluding failure of the component during the demanded service life with the greatest possible reliability.

Oil cooler module as an example of a plastic part with high functional integration
(photos: TiK)

Confidently Towards Series Production Maturity

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The construction of highly integrated plastics parts which combine several complex functions in one injection molding is a technology trend which had already taken over many areas of vehicle technology a number of years ago. Whereas mechanically less sophisticated drafts were predominantly created in the early days of this development, present-day concepts exploit the whole bandwidth of the mechanical, thermal and chemical properties of the polymers used to produce parts offering optimum weight and cost savings with at the same time high operational reliability. The growing demands on material and component, however, also lead to higher demands being made on the specimen testing.

With the aim of creating sustainable individual mobility, automobile manufacturers and their suppliers are cooperating in order to find innovative solutions for parts which are lighter and less expensive than the series-production parts to date. This is achieved by the systematic combination of different individual parts in one integrated system component which unites different complex functions.

One example of this development is the cylinder head cover: After initial substitution of the original metallic material by polyamide without expanding the function, the material potentials were gradually exploited and further parts were integrated, starting with simple mounting elements for cable guides or oil mist separators. Modern developments in the area of the cylinder head covers combine not only these classic elements, but also add further modules such as pressure control valves and parts of the inlet duct, while at the same time permitting the manufac- →

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ture of the whole system in a highly automated series production process.

One reason why, despite years of development experience, there are still potentials for component optimization is not least the ongoing further development of the available polymer materials, the growing possibilities of computer-aided component design and development and the increasing cooperation between different disciplines in the stronger coordination of the development processes. One area which is becoming ever more important within this technology trend is the testing of the specimen parts for validation of the function and lasting operational safety. The critical consideration of the duration of the testing phases in the scheduling of the component development is of particular importance for the punctual achievement of the milestones for series production maturity.

Virtual Component Testing at the Computer

With the growing performance of modern computer systems and the software for design engineering and numerical simulation of the structure and fluid mechanical material behavior, virtual component planning, design and testing has made great advances and will continue to grow in importance in the future. Simulation provides i.a. a valuable basis for gaining insights into complex mechanical load states and the resulting deformations. Last but not least, the imaging of the non-linear visco-elastic material behavior and the consideration of the anisotropic, i.e. direction-dependent, material properties enable ever more reliable predictions to be made on the component characteristics under simultaneous mechanical and thermal load. These advances result in ever more development steps being able to be carried out virtually, i.e. without the corresponding component tests on prototypes. This saves time in the development process, and thus significantly reduces the development costs.

Even though the results of simulations are becoming more and more reliable, they are no substitute for the validation of preproduction prototypes and series production parts. The reason for this is a wide range of material-specific and plastics processing variables and the material ageing which all influence the behavior of a plastic part without it being possible to image these with sufficient accuracy by means of simulations. Moisture content and temperature, for example, have a major influence on the mechanical behavior of polyamides. If, for example, a polyamide part through which coolant flows is operated in a hot engine environment, a complex state is created in the material which is characterized by a moisture and temperature gradient over the wall thickness. This state changes, furthermore, with increasing operating or testing time. Precise imaging of this effect in a numerical simulation is not possible using conventional methods, and is very difficult to measure in order to be able to validate simulation results which may be obtained.

Plastics-oriented Testing of Specimen Parts

Due not least to these limitation, the testing of specimen parts in trials remains the only way of investigating the behavior of a complete system that generally consists of polymer component, metal inlays and elastomer seals. The problem when carrying out the test, however, is the long time required for simulation of the lifecycle and for testing the complex demands on a part. In order to keep the testing time as short as possible, not all the individual functions are tested sequentially for highly integrated parts. The conducting of a combination test with simultaneous application of the different loads is increasingly becoming the standard for component testing.

One example from practice that could be mentioned at this point is an oil cooler module **(Title photo)** from the coolant circuit of a modern automobile. Different mechanical, thermal and chemical load types occur simultaneously in this component: On the one hand, the plastic is exposed to hot fluids such as coolant and engine oil. In addition, oxidation is caused to the outer surfaces of the component by the oxygen in the ambient air at high temperatures. In this operating environment, the component has to withstand the mechanical load collective of static internal pressure, cyclic alternating pressure loads, external forces and thermal stresses over a defined period of operation despite the challenging boundary conditions. Typical test periods here are of 3000 h under extreme load in order to ensure that the component constantly fulfils its function even under the toughest operating conditions.

Complex test apparatus and a complex control system are necessary in order to be able to test these combined loads in a single endurance test. **Figure 1** shows the set-up for such a test. A test set-up in which all the operationally relevant loads are applied in a single test run in order to shorten the testing time has one serious drawback as soon as a malfunction occurs in the component or material failure occurs and the damage analysis starts. The identification of the causes of failure and of the critical load combinations for the component is very difficult due to the large number of variables and demands a great depth of plastics engineering know-how. Research into the causes of failure has to taken into consideration not only the material proper, but also its processing and a detailed evaluation of the test parameters by comparison with the values demanded in the component specification.

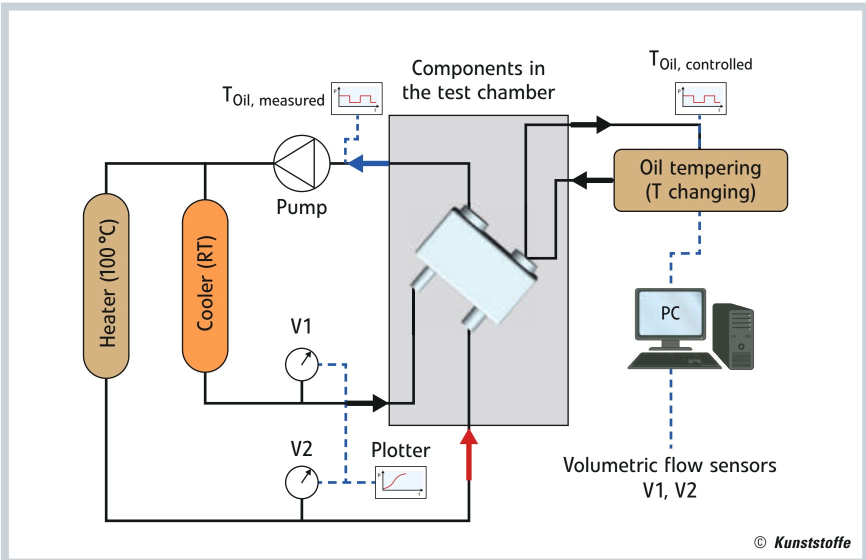

Fig. 1. Functional diagram of a combined test set-up

Approaches to Shortening the Test Duration

Particularly with plastic parts, the right choice of test parameters is important in order to be able to draw conclusions as to the behavior of the components during the application in the vehicle from the results of the test. The problem arises here that the loads occurring over the component lifecycle have to be simulated in accelerated form in order to remain within a reasonable test period. Various approaches are used here which allow a component lifecycle of ten years to be simulated within a test period of a few weeks or months.

One possibility of reliably shortening the testing time is the time-temperature shift principle. This is based on the observation that in polymer materials, effects which take place at low temperatures over prolonged periods of time take place similarly but more quickly at higher temperatures. One such example is the creep under constant mechanical load. This means that within certain limits, the increase in the testing temperature is an admissible instrument for shortening the testing time. Material-specific transformation and transitional temperatures have to be observed here, however, above which the time-temperature shift principle is no longer valid.

A further common approach used to shorten the testing time is to multiply the test loads by an exaggeration factor. It is hereby assumed that a small number of large loads damage the material in a similar way to a large number of smaller loads. For cyclic loads, this exaggeration factor is generally coupled to an increased frequency of the load application in order to achieve the necessary number of load cycles as quickly as possible. All the methods mentioned above for shortening the testing time reach their limits as soon as the response of the polymer to different load types changes due to the non-linear visco-elastic material properties and it leaves the linear range (**Fig. 2**). In view of these non-linear effects, for example, the cycle time of the internal pressure load cannot be reduced indiscriminately without having a significant influence on the material behavior: A polymer subjected to an impact load generally has a more rigid and brittle behavior than a part tested under quasi-static load. A further effect of significance here is that with increasing excitation frequency, internal friction can cause heating of the part and have a major influence on the material and component behavior. The superimposition of these two effects highlights the complexity of the influence of the test parameter on the part behavior, and shows the necessity for a profound understanding of polymer technology to enable practice-relevant and realistic planning and performance of the part tests.

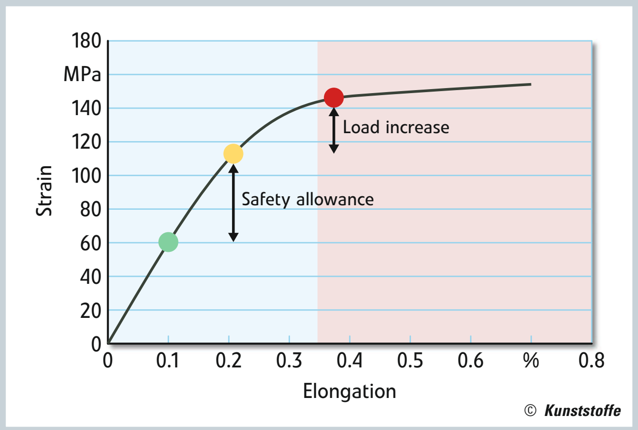

Fig. 2. Material engineering limits of reducing the testing time

Organizational Test Duration Optimization

Organizational measures can frequently also create further potentials which, although not accelerating the test as such, can result in time savings. Before the initial sample of a series production part undergoes the endurance test described according to the OEM (Original Equipment Manufacturer) specification, individual tests covering the critical load situations are carried out on preproduction series samples to obtain the technical approval.

Figure 3 shows the fundamental development process in which the planning of the internal and external tests is integrated. Time savings potentials can be identified here with generally short-time tests increasingly being carried out internally to bring the parts to the next-higher development level before they are sent to external institutions or the customer for time-consuming component tests. A component FMEA (failure modes and effects analysis) is recommended here to identify these short-time, internal part tests. Both the in-house tests and the cooperation with external service providers show time and again that efficient communication and close cooperation can help avoid a great many misunderstandings and hence lost time. The test conditions should be clarified and defined together with all the departments involved and with the external service providers right from the outset. Binding responsibilities and corresponding deadlines →

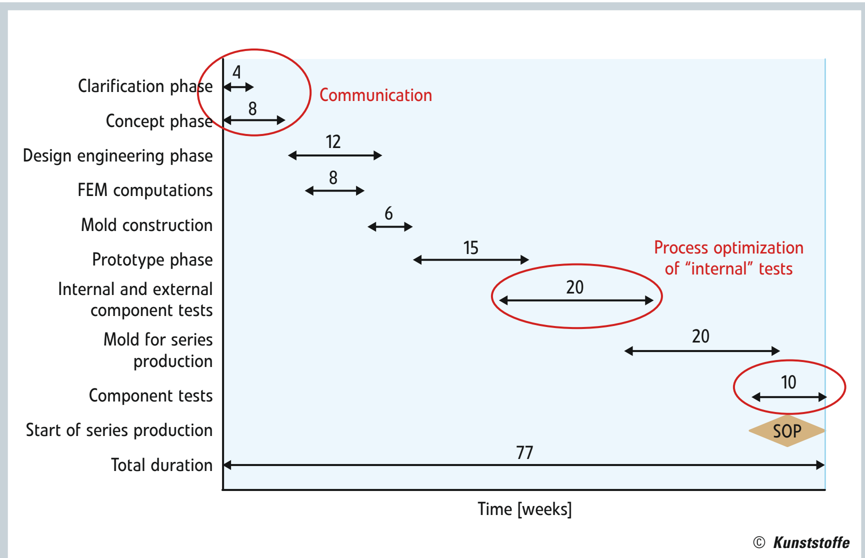

Fig. 3. Potentials for the reduction in development time (SOP: start of production)

should be laid down even at this stage. This includes i. a. the procurement of the parts to be tested, attachments, jigs and test media. During the planning and implementation phase of the part testing, a regular status report helps give everyone involved an overview of the progress of the tests. Deviations from the time schedule, for example, can thus be recognized at an early stage and, where necessary, corresponding measures can be initiated in good time.

Predicting the Service Life

By contrast with parts made from metallic materials, the exact prediction of the service life of plastic parts is a complex task. One reason for this is the limited number of Wöhler diagrams available for technical plastic compounds which establish the relationship between the load applied and the number of load cycles which the part can withstand. This is dictated by the complex, non-linear material behavior described above and the far more prominent influence of factors such as frequency, temperature and media contact on the fatigue behavior by comparison with metals.

In order to ensure a reliable component function over its lifecycle, tests are carried out on the parts according to various standards, specifications or requirement books. The standards are drawn up by technical committees of national or international standards organizations. These committees comprise experts from universities, testing institutes and representatives of companies from the relevant industries [1]. The specifications are generally drawn up by the client or ultimate user, in the automotive industry for example by the OEM. All the demands to be satisfied are defined here by specialists from the relevant technical departments (e. g. material and component).

Although the tests of the above-mentioned demands determine the serviceability of the tested part, they do not allow any prediction to be made as to the absolute service life of the component. In order to nevertheless rule out any failure of the component during the demanded service life with the greatest possible reliability, close cooperation is necessary between design engineering, simulation, part validation and materials experts in the definition of the test parameters. Today these departments are strictly separated in most companies. It would be desirable here to create a defined, multilateral exchange of information and know-how between the different disciplines without sacrificing the core competences of the individual faculties.

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Conclusion and Outlook

Innovative ideas, higher performance capabilities of computer systems and software for part development and continuous advances in the development of short fiber-reinforced polymer material compounds are steadily opening up new fields of application for highly integrated plastic parts.

The possibilities for part validation also have to keep pace with this development, because only through real, application-oriented test conditions which take into consideration the mechanical loads and material ageing caused by temperature and chemical media is it possible to make predictions about the part service life that can be achieved under real operating conditions.

Special knowledge of the polymer materials, their processing and the interaction between part and test is necessary for the evaluation and interpretation of the test results.

Since a shorter development time can offer significant cost savings, the possibilities for reducing the duration of a part validation should be exploited to the full. The special characteristics of the plastic material must, however, also be taken into consideration in order to obtain reliable and meaningful test results.

Last but not least, the organizational possibilities offered by circumspect project management also represent an important element for reducing the development and testing time. ■

REFERENCES

1 www.din.de, Deutsches Institut für Normung e.V., 01.12.2011

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