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ULTRASIM[R] Integrative Simulation Technology on the Development of Automotive Plastic Parts

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ABSTRACT

To enhance the CAE accuracy, the definition of material behavior is one of key influence on the result. In case of plastic material with fiber reinforcement, the anisotropic material behavior should be taken into account to increase of CAE accuracy.
BASF has developed an innovative CAE tool, ULTRASIM[R], which is capable of generating material models of thermoplastic materials for structural simulation. ULTRASIM[R], not only the glass fiber orientation effect, but also the weld line effect, tensile-compression anisotropy, strain rate effect are combined in a non-linear material law, which will be evaluated in a unique failure criterion, thus resulting in an highly accurate CAE approach.

1. Preface

The simultaneous demand for lighter and safer parts is a continuous challenge for the automotive industry. On-going efforts to bring down costs and reduce development times also demand that automotive parts be optimized at a very early stage. In order to achieve such goals, plastic materials have played an important role. Plastics can contribute to the following benefits, including weight reduction, lower manufacturing cost, enhanced design freedom, and unique material properties (e.g. good chemical resistance, good abrasion/friction resistance, low thermal conductivity). To achieve an optimum plastic part design which can fulfill all technical requirements of each application, a strong technical support is essential

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BASF is capable of providing such powerful support, including new material development, parts testing, process technology research, and computer aided engineering (CAE).

CAE is an essential and effective tool at the product development stage, since CAE can be used to predict behavior under tests and to optimize injection molding parameters. Using the CAE simulation technology, development time can be reduced by decreasing the number of trial molds and evaluation tests. In addition, visualization of behavior upon testing is valuable in order to identify the root cause of the problem and find effective solution. Behavior of polymers at various temperature differs from other materials, such as metals. Typically, polymers show dependencies on environmental factors such as temperature and moisture. In addition, injection molding parameters and resultant material status, such as weld lines, will affect material mechanical properties. Reinforcement glass fibers that induce direction dependent property can be another factor of anisotropy, for instance glass fiber orientation.

Upon testing, loading parameters such as speed and types (i.e. tensile, compressive, shear, asymmetry) can induce unique behavior of polymers.

Because of this, generally CAE software is not capable of predicting the behavior of plastic material accurately. This could result in the following:

1. Successful but over-engineered design. This type of design still has room for improvement in terms of weight reduction.

2. Failed design. Due to incomplete estimation of plastic behavior, experimental behavior differs from the one predicted by CAE.

BASF has developed an innovative CAE tool, ULTRASIM^R, which is capable of generating material models of thermoplastic materials for structural simulation. ULTRASIM^R is based on a new and modern approach to numerically describe the behavior of thermoplastic material laws into CAE. One unique characteristic of ULTRASIM^R is that, for structural simulation, it can consider material anisotropic properties caused by processing.

Fig. 1- ULTRASIM^R revolutionary features

2. ULTRASIM^R Features

2.1 Glass Fiber Orientation Effect

In order to withstand severe requirement, such as high strength and high temperature, one common method of reinforcement is to add short Glass Fibers (GF) to the polymer matrix. This reinforcement can improve overall performance of polymers, and thus, achieve technical requirement.

During the injection molding process, due to the shear flow along the skin layer (solidified polymer) and core flowing layer (melted polymer), the GF is force to orient along the thickness.

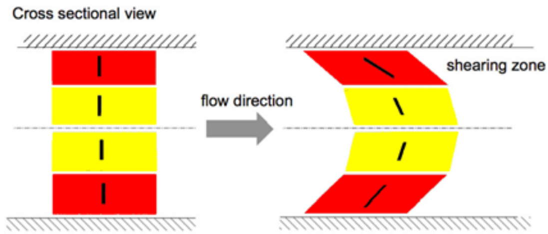

Fig. 2- GF orientation due to flow shear

Due to overall part flow, the GF oriented radially around the injection gate according to its design.

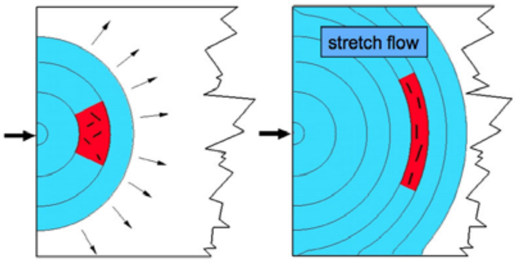

Fig.3- Stretch flow effect on GF orientation

All over the part, GF orientation shows non-uniform distribution depending on polymers, injection molding parameters, gate location, geometry, and rheological properties.

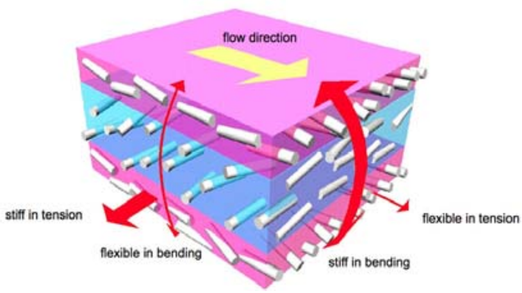

Fig.4- GF orientation along thickness and its effect on mechanical properties.

Each finite single area will have its own unique mechanical properties, according to the load direction. (Fig.4). The mechanical behavior as a component is influenced by GF orientation in thickness direction (Fig.2) as well as along the whole part (Fig.3). Depending on fiber content, this anisotropic GF orientation effect is a key indicator, resulting in unique stress and strain characteristics [1]. (Fig.5)

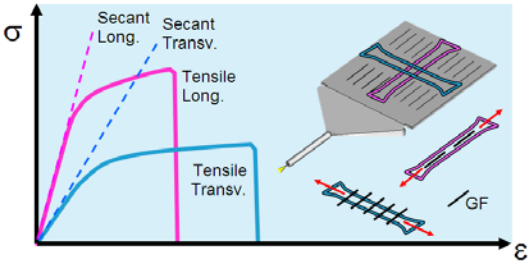

Fig.5- GF orientation effect on overall mechanical properties.

In order to simulate GF orientation of plastic components, BASF utilizes commercial injection molding simulation software, such as MOLDEX and AUTODESK MOLDFLOW. These software can predict GF orientation of plastic components along the thickness and along the part.(Fig.6)

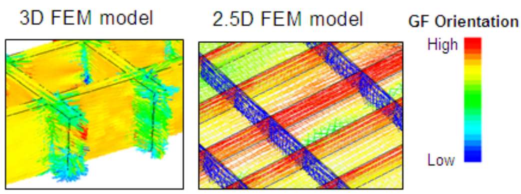

Fig.6- GF Orientation results (left 3D, right 2.5D FEM Model)

ULTRASIM^{R} uses the GF orientation results from injection molding simulation software (e.g. MOLDEX and AUTODESK MOLDFLOW) to create a local anisotropic material model for structural simulation. (Fig.7)

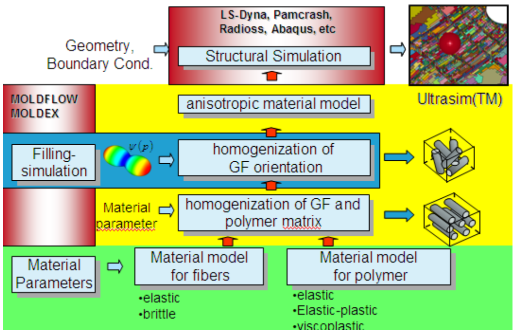

Fig.7- ULTRASIM^{R} Integrative Simulation

The two laws, which are viscoplastic formulation of polymer matrix and elastic model of GF, are combined into a micromechanical model to describe a composite material model (i.e. GF reinforced material). This micromechanical model follows a homogenization process based on Mori & Tanaka and Eshelby theories. (Fig.8)

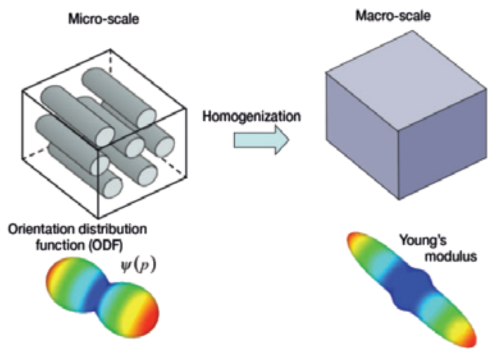

Fig.8- Theoretical model of homogenization.

2.2 Strain Rate Dependency Effect

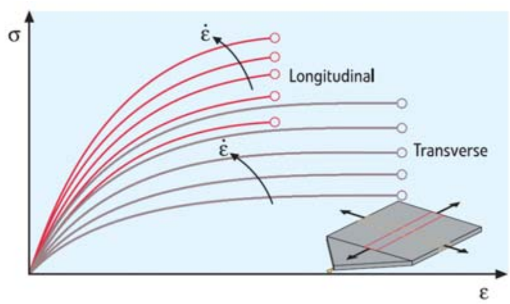

Fig.9- Strain rate dependency on mechanical properties

In addition to GF anisotropy, strain rate influences mechanical properties, because of hardening effect of plastic upon loading at high speed. (Fig.9)

A general stress-strain curve is used in CAE analysis to predict behavior of thermoplastic material. Such test, based on ISO standard for example, is defined to test with a speed of 5 to 50mm/min using an effective length of 105mm with an ISO test specimen. This tensile speed corresponds to strain rates between 10^{-3}/s and 10^{-2}/s. However, at crash loadings, an instantaneous impact load could result in strain rate up to 10^{3}/s. Under this condition, plastic materials show higher mechanical properties than the ISO test[2]. (Fig.9)

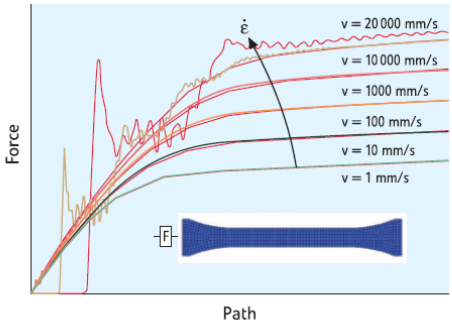

Fig.10- Strain rate dependent strain-stress curves

The stress strain curves shown in Fig.10 are determined by an optical measurement system developed by BASF. Using this developed measurement system, the material properties at high strain rate is measured. This material data is vital to simulate part's behavior for impact situation.

2.3 Tension–Compression Asymmetrical Effect

As mentioned above, an accurate simulation of GF reinforced thermoplastic still is a big challenge. The non-linear behavior of polymer can be influenced by GF orientation and Strain Rates. Additionally, plastics have failure strength in the compression range that is considerably higher than that of tension (Fig.11).

ULTRASIM^R technology also take into account this tension-compression asymmetric behavior when building up the local anisotropic material model for structural simulation. (Fig.7)

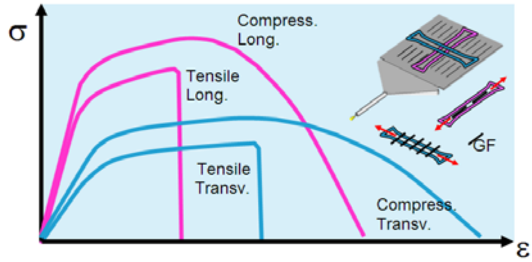

Fig.11- Tension-Compression Asymmetrical Effect

2.4 Material Failure Criterion

One important factor to precisely predict the plastic part behavior is to establish a numerical material model that simultaneously includes main polymer characteristics, such as GF orientation, strain rate, and tension/compression asymmetry.

BASF is able to predict such unique performance by using the micromechanical model of ULTRASIM^R. BASF also created a material failure criterion at ULTRASIM^R based on upon discussed factors[1]. This failure model considers GF orientation, temperature, water content, strain rate and tension-compression asymmetry. Failure occurs if the polymer matrix fractures, the fibers break, or the matrix becomes detached from the fibers.

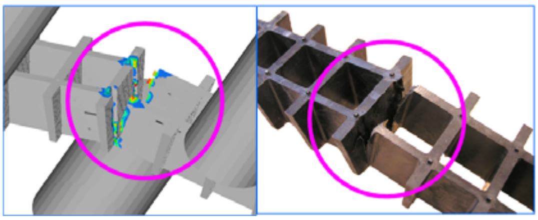

Fig12- BASF ULTRASIM^R Simulation and testing results

3. ULTRASIM^R for Plastic Development

ULTRASIM^R has been used to support development of plastic parts. With this tool, material replacement from metal to plastics has been successfully achieved even for highly loaded applications including torque rod and highly stressed applications, such as oil pan.

For plastic torque rod, ULTRASIM[R] has provided integrative simulation along with optimization technology at the development stage. This development support process has achieved affordable yet optimal plastics design while accomplishing the defined requirements (Fig.13).

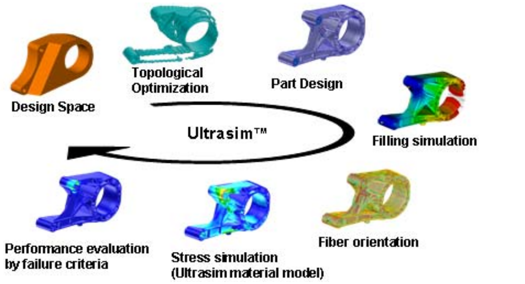

Fig.13- Development Cycle with ULTRASIM[R] Integrative Simulation

Based on results of processing simulation including GF orientation and location of weldlines, ULTRASIM[R] has modeled resultant material properties and estimated the location of failure initiation correctly. (Fig.5) The testing as well as CAE simulation with ULTRASIM[R] have shown that failure initiates at a fixation point, where weld line exists and GF orientation is random.

CAE analysis with ULTRASIM™ has predicted the fracture to occur at a load of 15kN. The result of testing shows that the fracture occurs between 15.0 and 15.3kN.(Fig.14)

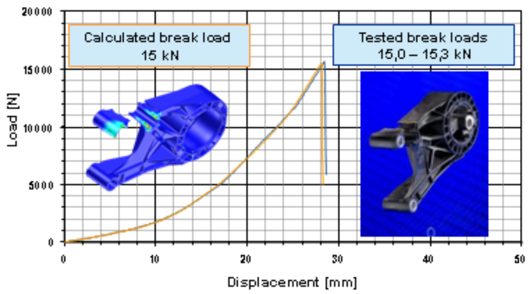

Fig.14- CAE result with ULTRASIM[R] Integrative Simulation and Testing Result.

Another example where ULTRASIM[R] was used to support the development of plastic part is the transmission cross beam for the BMW 5 Series.(Fig.15)

This is the first transmission cross beam made of plastic by using Ultramid® A3WG10 CR instead of aluminum, it was possible to reduce the weight of the part by 50% (rear part). In addition to weight reduction, development focused on optimum vehicle acoustics and crash safety. As proven by elaborate testing, these two goals were achieved.

Fig15- Transmission cross beam for the BMW 5 Series

Another example where plastic replacement is becoming a commodity is the oil pan.(Fig.16) BASF has four successful examples of plastic replacement on the market and several ones are under development.

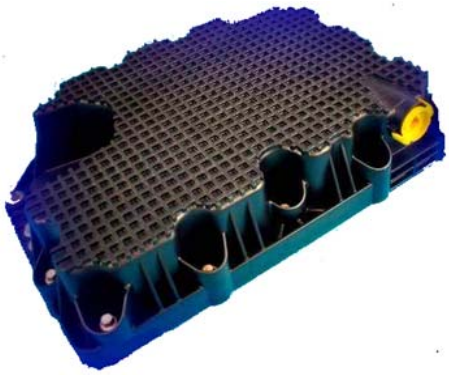

Fig16- Oil Pan for Ford Scorpio

Compared to conventional oil pan systems made from aluminum, the thermoplastic design freedom can allow for more oil content, which reduces maintenance needs by increasing the oil change intervals.

Engine noise generated by the plastic pan is also said to be less than with the thermoset version that was replaced[5].

These achievements were possible due to the part optimization using BASF engineers' know-how and CAE integrative simulation: ULTRASIM^R.

4. Conclusions

BASF has a developed a revolutionary CAE tool for increasing the accuracy of CAE simulations of thermoplastic materials. This system development was achieved at BASF's central technical center in Germany.

In this integrative simulation, not only the glass fiber orientation effect, but also the weldline effect, tensile-compression anisotropy, strain rate effect are combined in a non-linear material law, which will be evaluated in a unique failure criterion, thus resulting in an highly accurate CAE approach.

BASF is also working through new evaluations and theories necessary to better develop plastic parts, such as long-term dynamic loads: fatigue.[6]

To better use CAE as an effective tool in parts development, accuracy is an essential key factor. ULTRASIM^R has been playing an important role to fulfill these requirements. Continuous development is necessary from other pillar of CAE analysis, such as software, hardware, theory and method.

As a global partner, BASF supports the development of plastic parts by providing technical support based on technical centers throughout Asia as well as in Europe and the USA.(Fig.17)

Fig.17 BASF Technical Centers in Asia.

Referance

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