Talcum Particle Reinforced Thermoplastics Part I: Influences of Processing Conditions and Experimental Characterization

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Summary:

The properties of thermoplastic polymers considerably depend on the process of moulding, irrespective of the geometry of the part and the used raw polymer. Both, the structure of the polymer resulting from moulding and the weld lines occurred because of the complexity of the part, may show a large influence on different part properties. For analysing the influence of injection moulding on the resulting structural part properties, plates with different processing conditions are fabricated with Hostacom XBR169G, a polypropylene (PP) filled with rubber and talc, and Bayblend T65XF, a blend of polycarbonate (PC) and acrylonitrile butadiene styrene (ABS). The varied conditions are the melt temperature and the injection velocity. Afterwards different test samples, longitudinal and lateral to flow direction, are milled out of the fabricated plates. Using this extracted test samples, the true deformation and failure behaviour are measured by uniaxial tensile tests at different test temperatures and strain rates. The complex deformation behaviour is determined by the method of grey-scale correlation.

The analysis of uniaxial tensile tests shows anisotropic effects depending on the preparation direction of the specimen, i. e. in stress behaviour as well as in Poisson's ratio for Hostacom XBR169G. Also machine settings affect the anisotropic behaviour. A high mass temperature in combination with a slow injection speed leads to differences in stress level and Poisson's ratio. At low mass temperatures and high injection velocities, the plates solely show isotropic behaviour. In all experiments, the strain at rapture is not influenced by processing conditions or preparation direction. For Bayblend T65XF no anisotropic behaviour is found.

Keywords:

mechanical properties, polypropylene, talcum, reinforced, injection moulding, deformation behaviour, anisotropy

1 Introduction

Plastics play an increasing role in many areas of technical applications. Accordingly the modeling and numerical simulation of their behaviour under mechanical loads, especially at safety components, is of great importance. Even car door panels made of PP are now included in the vehicle simulation, with respect to EuroNCAP tests.

The deformation and failure behaviour of polymers is characterized by its structure of long-chain, entangled or networked macromolecules [1]. In typical production processes as injection moulding the microstructure of a plastic material is subject to considerable changes. Mechanical properties such as yield stress and strain at rapture of the same material can fluctuate considerably, depending on its history. For instance the flow of polymer melt causes orientation and stretching of the macromolecules and possibly also the phase morphology, which can lead to an anisotropic material behaviour. The use of material properties without consideration of the history, therefore, involves uncertainties, making high factors of safety in a constructional element necessary. For a better material utilization and a reliable design of components, it is therefore of great importance to know the influence of process conditions taking effect on the material at a certain location of a part, to understand its mechanical properties and incorporated those in the material description.

2 Preparation of the Sample

For the analysis of injection moulding induced property profiles, plates ($80mm$ x $80mm$ x $2,5mm$, see figure 1) were produced on the injection moulding machine FX-75 from Klöckner-Ferromatik-Desma. The material under consideration was Hostacom XBR169G from LyondellBasell, a polypropylene (PP) reinforced with talc and EPDM, and Bayblend T65XF from Bayer Material Science, a blend containing polycarbonate (PC) and acrylonitrile butadiene styrene (ABS). To show the influence of manufacturing conditions on the mechanical properties, the parameters melt temperature and injection velocity were varied in injection moulding of the plates for Hostacom XBR169G. This is shown in table 1. Other parameters as mould temperature, holding pressure and cooling time were not changed (see table 2). In contrast no manufacturing condition for Bayblend T65XF was varied. Subsequently samples were milled out of the plates longitudinal and lateral to the flow direction. The choice of suitable samples is shown in section 3.1.

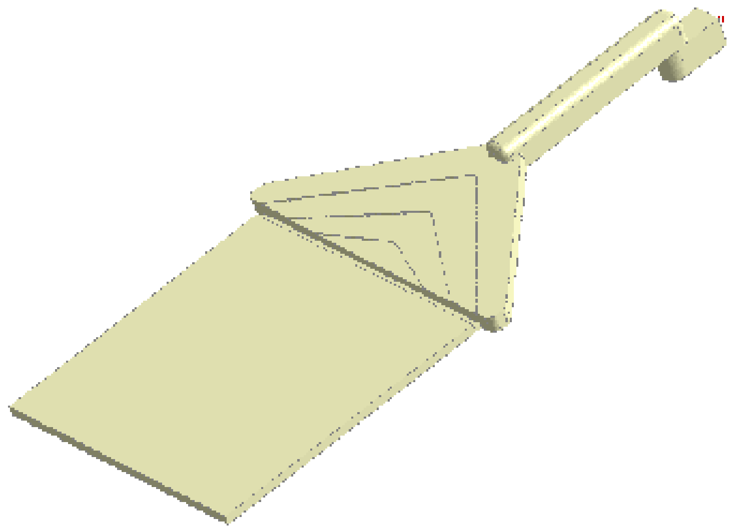

Figure 1: Injection moulded plate with delta gate

Table 1: Variied process parameters for Hostacom XBR169G

	melt temperature $[°C]$	injection time $[s]$
S1	240	4
S2	200	0,5
S3	220	2

Table 2: Process parameters

		Hostacom XBR169G	Bayblend T65XF
melt temperature	$[°C]$	see S1, S2, S2	280
mould temperature	$[°C]$	40	85
injection time	$[s]$	see S1, S2, S3	2
holding pressure	$[MPa]$	40	40
holding time	$[s]$	30	30
cooling time	$[s]$	20	20

3 Method of Experiment

The analysis of the crash behaviour of plastics is proposed to reach high strain rates in the examined samples area. The strain rate appearing under an applied load, neglecting all the above-described factors, depends on the machine speed and the geometry of the sample. Both parameters can not be varied arbitrarily. Machine and measurement technique limit speed and sample geometry and thus the theoretical achievable strain rate.

For universal use in constant or variable strain rate servohydraulic high-speed testing machine is used [2]. By suitable sample geometries and testing devices different states of stress can be realized. The functioning of this testing machine is shown in the schematic design of figure 2.

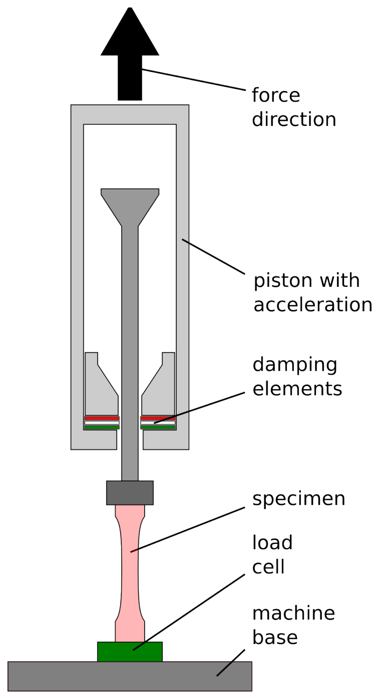

Figure 2: Schematic setup of the servo-hydraulic testing machine

The dynamic uniaxial tensile tests were performed on the servohydraulic testing machine HTM5020 (max. $20m/s$; $50kN$) from Zwick at $T = 23°C$ and the quasi-static were done on the universal testing machine Z020 from Zwick (max. $750mm/min$; $20kN$) at $T = -35°C$, $T = 23°C$ and $T = 80°C$. For each trial five retries are performed.

3.1 Sample Geometry

In the study by JUNGINGER [3] a tensile bar is used, which is designed based on the geometry 1A of DIN EN 527. Because of the short parallel range of $5mm$ high strain rates can be achieved. A disadvantage of this sample is the small area of the parallel range. Because of the low width, there is a risk that edge effects influence the results. The long inlet radius and the short parallel area can lead to a not straight uniaxial stress state. In addition, a larger area in the parallel region of the sample would be favourable for the strain measurement using grey scale correlation. The stochastic pattern is easier to create and the analysis can be based on a larger number of facets.

In the study by BECKER [4] two sample geometries are introduced, which are rated to their suitability for high-speed tests. These new geometries, Z30- and BZ-geometry are shown in figure 3. The Z30-sample is a shortened tensile bar in accordance with DIN EN 527 Type 1A, which features a wider parallel area in terms of a good optical strain measurement and is designed for quasi-static tests. The BZ-sample is a combination of the two previous samples, with a short but wide parallel area. BECKER was able to show that the new designed BZ sample achieves all requirements of high speed tests. Both the strain rate constancy and a uniaxial stress state in a large area of the sample could be verified [4].

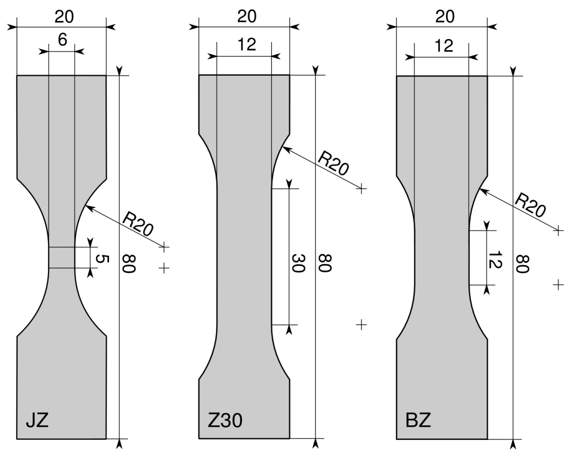

Figure 3: Different sample geometries for the tensile test

3.2 Strain measurement

Effects such as the necking of the tensile bar in the plastic region lead to large local differences in the deformation of the sample. This requires a local strain measurement. The strain determination by measuring the crosshead displacement can not be used, since it only includes an average strain value over the entire sample length.

A suitable method for recording the entire strain information during a test is the grey scale correlation [1, 2]. In this method, a stochastic pattern is applied to the sample (see figure 4) and filmed with a digital camera during the test. The required frame rate is, for example at a haul-off speed of $6m/s$ and ductile material behaviour, at about 36.000 frames per second, for quasi-static experiments at 2 frames per second. Following the experiment the displacements and distortions of the pattern between the stored images can be calculated using a cross correlation algorithm [5]. For this the whole picture is divided into individual facets of constant facet size and constant facet distance. From each of these individual facets a vector of displacement is calculated.

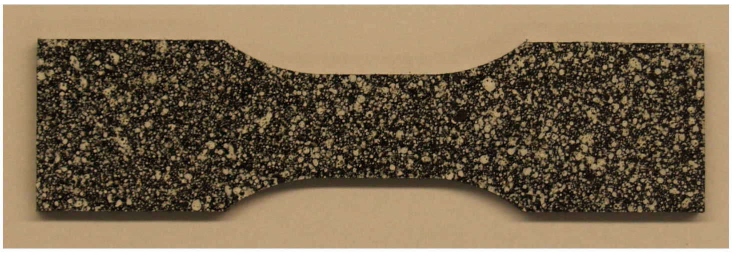

Figure 4: Tensile bar with grey scale pattern

From the calculated displacements of the facets between two images, the strains result on the entire sample surface. The correlation procedure can be performed with a single camera with two-dimensional analysis, or with two cameras and three-dimensional analysis. After the image correlation, the local displacement and strain distribution on the sample surface is available for each picture taken, as shown in figure 5. To calculate the local strains during the experiment, the two-dimensional strain information from the correlation has to be converted for each time step in a one-dimensional value. This is done by averaging a certain number of facets, which can be chosen either absolute or relative to the measured strain. In the later presented results an averaging area of $2mm$ was chosen in the direction of loading on the entire sample width.

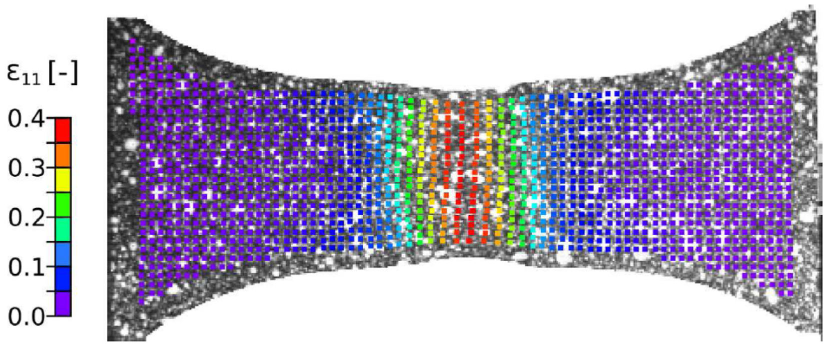

Figure 5: Correlated single picture including single facets

Finally, the calculated strain is combined with the measured force signal to calculate the resulting stress-strain diagram. For the dynamic tests, the force signal was filtered, since structure and location of force measurement on the test machine and the impulsive coupling of the force in such systems always result in vibrations in the recorded force signal, which correspond to the natural oscillations of the system. A detailed description of the filter method is depicted in [4].

4 Test Results

In the following section the results of tensile tests are presented. In details the selection of the polymer, as well as the influence of process parameters, the test temperature and strain rate are analysed. These measured material properties are the basis for the material model used for crash simulation, see HEMPEL und SEELIG in [6]

4.1 Influence of the Extraction Direction of the Sample

To show the influence of used polymer to the resulting mechanical properties, the stress-strain behaviour of Bayblend T65XF and Hostacom XBR169G is shown in figure 6 .

The material Bayblend T65XF shows no anisotropic effects; the true stress-strain behaviour shows no difference, depending on whether the tensile bars are taken longitudinal and lateral to the flow direction.

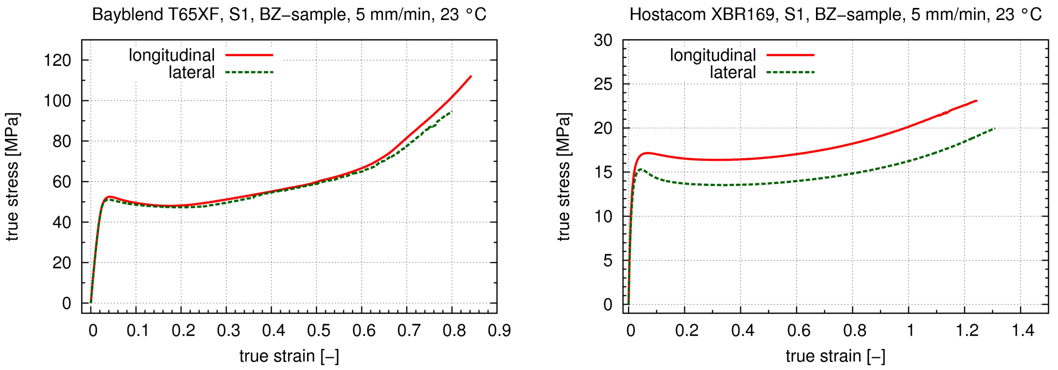

Figure 6: Stress-strain-behaviour; left: Bayblend T65XF; right: Hostacom XBR169G

However, Hostacom XBR169G shows differences in the deformation behaviour. The stress level of samples that are taken longitudinal to the flow direction is about $20\,\%$ above the stress level of samples taken lateral to the flow direction for the setting S1.

In addition to the already shown anisotropy in the stress-strain behaviour, Hostacom XBR169G shows a higher Poisson's ratio up to $60\,\%$ for tensile bars taken along the flow direction (see figure 7). The lateral strain behaviour of Bayblend T65XF otherwise, shows no anisotropic effects, the Poisson's ratio is not different for samples prepared longitudinal and lateral to the flow direction.

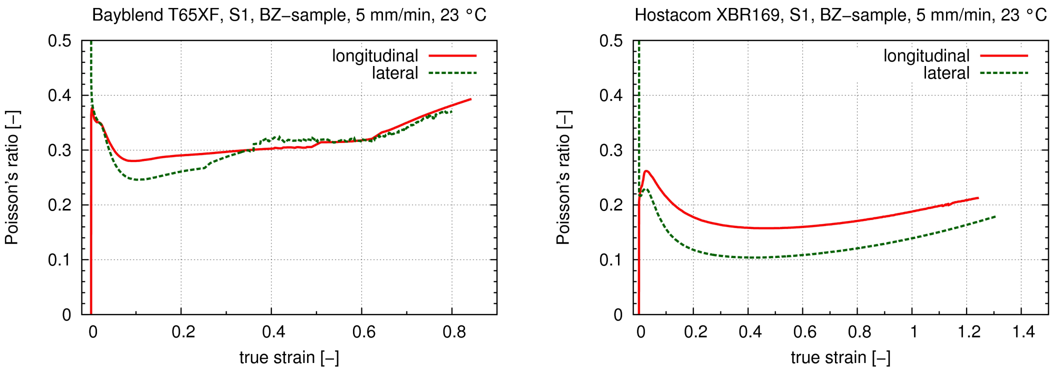

Figure 7: Poisson's ratio for Bayblend T65XF (left) and Hostacom XBR169G S1 (left)

The different degree of anisotropy in different polymers, can have several reasons. An orientation of the talc particles could occur in Hostacom XBR169G, which align themselves along a preferred direction in the filling process during injection moulding. This would result in a reinforcing effect, if the loading direction coincides to this preferred direction. Similarly an alignment of the EPDM would be possible; the rubber spheres could deform during the filling process by the high shear forces and also align along a preferred direction. To clarify this issue, images with a scanning electron microscope were made. In figure 8 the fracture surface of a tensile bar made of Hostacom XBR169G is shown, which was produced by cold shortness. As expected, a preferred orientation of the talc particles can be observed in the flow direction. Similar results are shown by ZHOU and MALLICK [7]: they present anisotropic effects which are created by injection moulding. The injection moulding process influences skin-core morphology exhibiting different orientation of talc particles in the skins than in the core.

4.2 Influence of Process Parameter

As described in section 2, the influence of process conditions in the injection moulding process is analysed. Besides setting S1 additional settings have been selected, whose influence on the deformation behaviour is shown in figure 9.

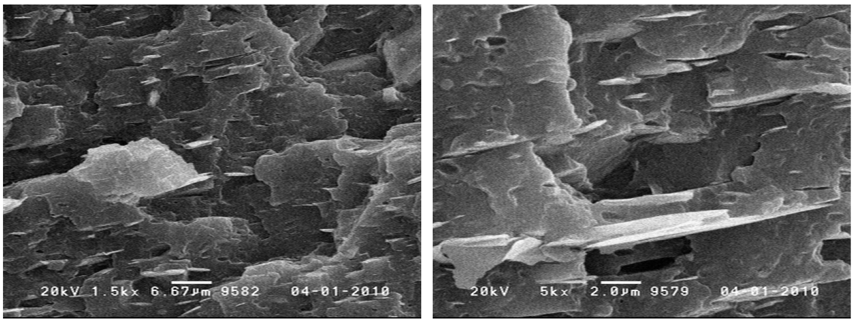

Figure 8: SEM pictures with magnification 1500 (left) and 5000 (right)

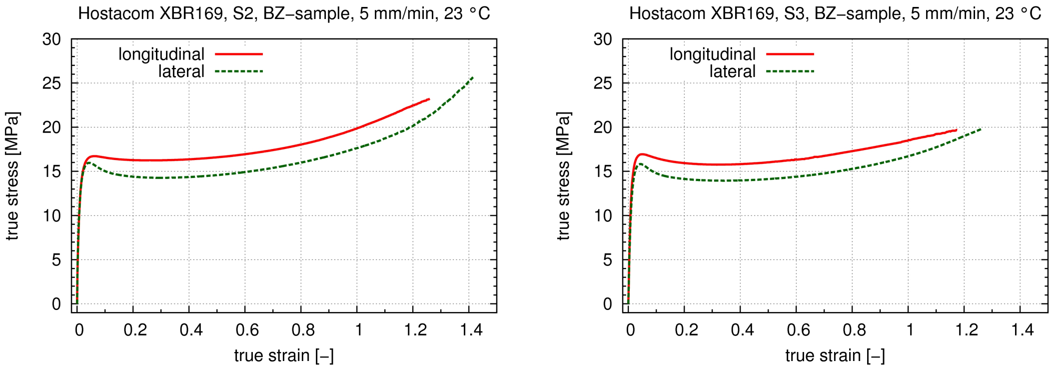

Figure 9: Stress-strain-behaviour for Hostacom XBR169G; left: setting S2; right: setting S3

In contrast to the setting S1 (see figure 7) the anisotropy in settings S2 and S3 is significantly less distinctive; the stress level shows differences of just less than 10%. The differences in lateral extension are also very low. The choice of a higher melt temperature, in combination with a low injection rate, leads to the most characteristic anisotropy. It is currently investigated by injection moulding simulations, how the various manufacturing parameters affects the filling process in injection moulding. Perhaps the slow filling process results in lower melt temperatures, which would increase the shear forces taking effect on the talc particles. This could lead to a preferred orientation of the talc particles.

4.3 Influence of Testing Temperature

To generate a complete material data set as the basis for a material model, the influence of test temperature on the quasi-static deformation behaviour of Hostacom XBR169G is shown in figure 10.

At all temperatures ($T = -35\,°C$, $T = 23\,°C$ and $T = 80\,°C$) the setting S1 shows a significantly higher stress levels in samples which were taken longitudinal to the flow direction. The differences are measured at $T = -35°C$ and $T = 23°C$ at 20%, while the difference at $T = 80\,°C$ is smaller, and continues to increase with increasing strain.

4.4 Influence of Strain Rate

For a complete material data set not only temperature dependence, but also the influence of strain rate is important [8]. This is shown in figure 11 for Hostacom XBR169G at setting S1.

As with the measurements of temperature dependence, Hostacom XBR169G indicates an anisotropic material behaviour at different strain rates. The stress differences, depending on the strain rate, move in the range of $10\% < \sigma < 20\%$ between samples taken longitudinal and lateral to the flow direction. These differences can be explained with an orientation of the talc particles as described in section 4.2.

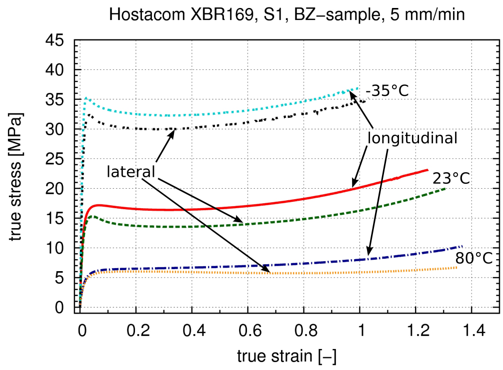

Figure 10: Influence of testing temperature for Hostacom XBR169G at setting S1

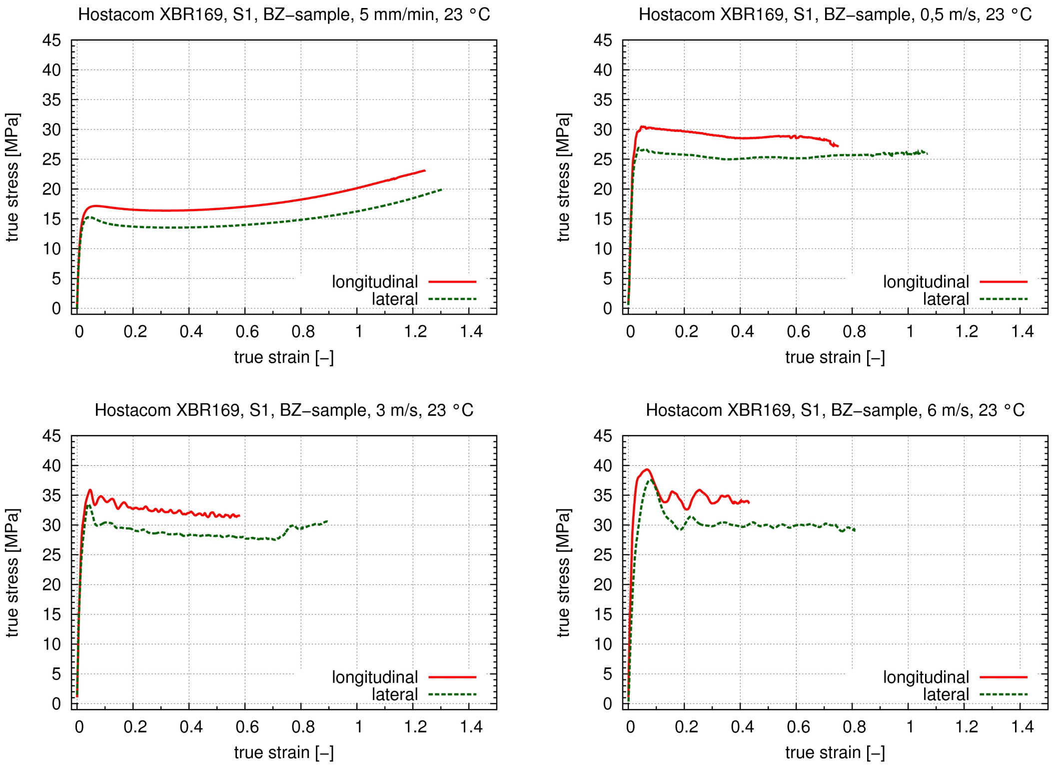

Figure 11: Stress-strain-behaviour for Hostacom XBR169G at setting S1 at various strain rates

5 Summary and Outlook

The aim of this study is to create a basis for a material model for crash simulation, taking into account an anisotropy induced by injection moulding. The researches shows that this anisotropy in Bayblend T65XF, a blend of PC and ABS, does not occur. In contrast, Hostacom XBR169G, a PP filled with talc and EPDM, shows signified differences in stress levels both at high strain rates and at different test temperatures. These differences for tensile bars, which are taken longitudinal and lateral to the flow direction of injection-moulded plates, vary depending on the selected injection moulding setting.

The calculated stress-strain curves in combination with the measurement of strain depending lateral extension at different strain rates and test temperatures are used by HEMPEL and SEELIG [6] for a basis to create a material model for Hostacom XBR169G and its application in crash simulation.

In the future, the prepared samples will be analysed using SEM and TEM to explain the occurrence of a anisotropy depending on injection moulding settings. Approaches for an alignment of the talc particles have already been explained. Furthermore, the influence of injection moulding setting is further analysed, using other plates produced under different injection moulding settings. Through these researches it will be possible to explain the measured stress differences depending on orientation.

6 Acknowledgement

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7 Literature

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