# MODELING OF SHORT FIBERS COMPOSITES STRENGTH WITH USE OF FAILURE INDICATORS

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**ABSTRACT**: Presented work is focusing on numerical simulation of short glass fibers reinforced thermoplastic composites produced with injection molding technology. A combination of commercial software packages for: injection molding analysis (two leading systems), material modeling (Digimat) and structural analyses (Abaqus) enables computer simulations of mechanical behavior incorporating information on fibers distribution. Such approach allows prediction of mechanical response much closer to reality and with the use of failure indicators a critical load could be estimated. A series of tensile tests on injection molded samples were conducted in order to compare presented simulation approach with reality.

**KEYWORDS**: Injection molding, short glass fibers, mechanical performance, failure indication, computer simulations, Digimat, Abaqus

## INTRODUCTION

Thermoplastic materials are more and more often used to replace thermosets and metals in demanding applications were complex loads are applied. Such a replacement becomes feasible thanks to increasing mechanical performance of new polymers as well as short fibers reinforcement. However, introduction of short fibers leads to anisotropic material properties caused by fibers orientation induced by injection molding process. This phenomenon can hardly be modeled numerically with available simulation tools for structural analysis. Since general-purpose FEM packages are able to model anisotropic material properties, they require explicit definition of fibers orientation provided by the user. The aim of this work is to develop and evaluate an approach for comprehensive mechanical analysis of short glass fiber reinforced product, covering both – production phase and testing process.

## EXPERIMENTAL RESULTS

Tensile modulus and strength provided in material datasheets are measured according to ISO 527 standard on samples that are in most cases directly molded. Such members are characterized by very high degree of fibers orientation in flow direction i.e. in the direction of tensile load during testing. Degree of orientation can reach 90%, what makes the sample almost unidirectional thus its mechanical response is significantly stiffer in comparison to samples taken from real parts. As an example, in Fig. 1 a comparison of tensile responses of samples made of polyarylamide reinforced with 50% glass fibers with different degree of fibers orientation is presented, where curve: A – corresponds to directly molded sample; B – represents results of the sample machined from 150x150x2mm plate in the flow direction; C – represents results of the sample machined from the same plate, but in the direction transverse to the flow; D – represents results of the sample machined from the same plate but at 45° angle to the flow direction.

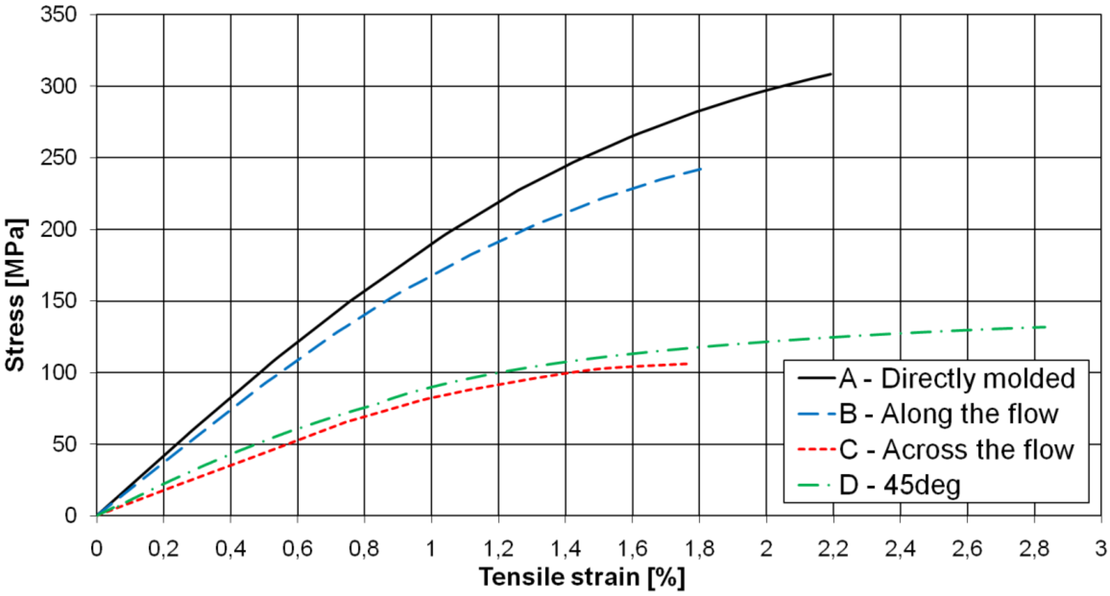


Fig. 1 Comparison of tensile test results for polyarylamide 50% glass fibers in case of different orientation of short fibers

In case of the sample machined in flow direction (Fig. 1; Curve B), which represents highly oriented state on real part, tensile modulus and strength are about 20% lower compared to directly molded sample (Fig. 1; Curve A). The sample machined transverse to the flow direction (Fig. 1; Curve C) failed at about 35% of the maximum load which can be carried by directly molded specimen.

The main conclusion from analysis of experimental measurements for different degree of orientation is that for prediction and optimization of mechanical performance of reinforced thermoplastic parts the fibers orientation must be taken into account, as the local material modulus and strength are highly dependent on it. It should be also mentioned that proper understanding of stress values is possible only when local fibers orientation is known. Strain values in such a case could be considered as a better measure of composite behavior but the tensile strength cannot be accurately predicted.

## DESCRIPTION OF SIMULATION APPROACH

Designing of thermoplastic parts is very often aided by numerical simulations. In case of composite materials it is necessary to take into account the influence of the orientation of reinforcing fibers, in order to obtain accurate results of structural analyses. The easiest and most often applied simplified method is based on reduction of the material stiffness by the given factor, usually equal to 20%. The amount of the correction is a result of the comparison analysis of tensile tests made on samples which are directly molded (according to ISO 527) and cut out from molded plates. The reduction of the stiffness is meant to model the varying orientation of fibers, but the material description remains isotropic, so it has the same properties in all directions throughout its volume. In an alternative, more advanced approach the orientation of fibers is directly taken into account in the structural analyses. In such an approach the calculations must start with the simulation of injection molding process of analyzed part. In the work described in this paper two leading systems available on the market were used. The fiber orientation being the result of these simulations is then utilized in structural analyses, which were conducted in Abaqus FEA software package. The transfer of orientation results was realized indirectly with use of Digimat software. As an input to Digimat the properties of each composite phase are provided and the software, through the homogenization process, calculates resulting mechanical properties of the composite material. Additionally, Digimat to CAE module takes the value of orientation tensor coming from the injection molding simulation and calculates orthotropic material properties for each finite element of the numerical model of analyzed part, which are used in calculations of Abaqus FEA. In Fig. 2 the diagram of described approach is presented.

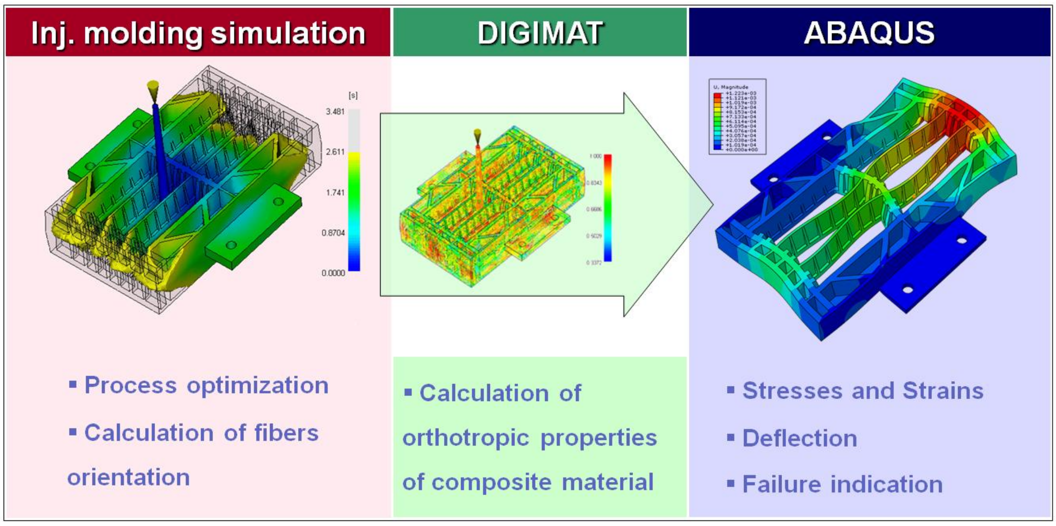


Fig. 2 Simulation approach for short fiber reinforced thermoplastics processed by injection molding

## VIRTUAL TENSILE TEST

Verification of the simulation approach has been initiated with the tensile test performed according to ISO 527 standard in order to start with the simplest possible geometry of the sample. One of the key factors influencing the mechanical response of composite is prediction of the fibers orientation. Therefore it has been decided to use and compare the results of two leading injection molding simulation systems available on the market (Simulation 1 and Simulation 2). In Fig. 3 results of performed simulations are presented. Simulation 1 (Fig. 3, Curve A) overestimated stiffness of the material what results in underestimation of strain and deflection. In case of Simulation 2 (Fig. 3, Curve B) a much better fit to experimental result was achieved.

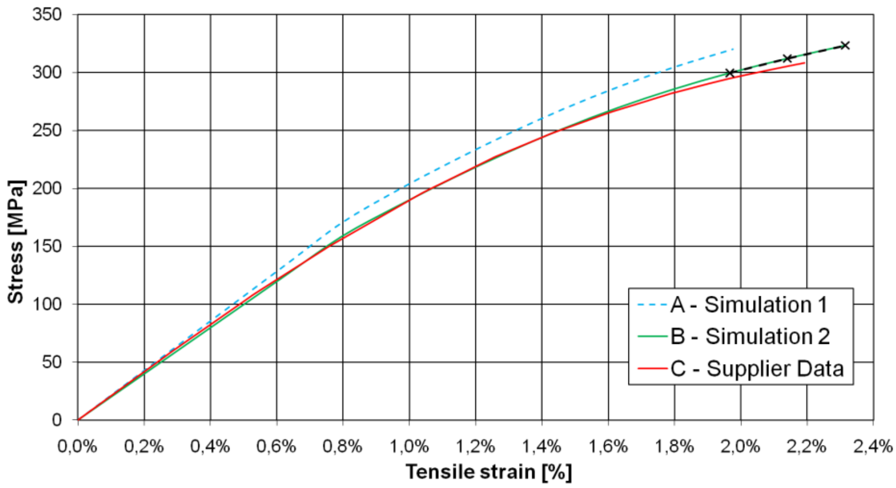


Fig. 3 Comparison of real and virtual tensile test results for directly molded ISO 527 sample made of polyarylamide reinforced with 50% glass fibers

In order to confirm the source of discrepancy for Simulation 1 (Fig. 3, Curve A) fibers orientation in directly molded sample was measured using cross-section method and microphotography. Results, presented in Fig. 4, unveil significant discrepancy in degree of fibers orientation being the main reason for overestimated material stiffness.

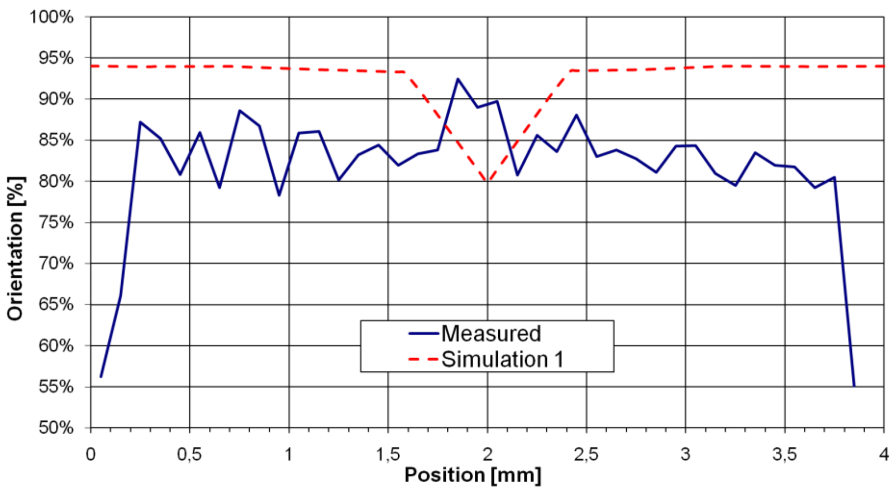


Fig. 4 Fibers orientation thorough thickness in directly molded ISO 527 sample (measured in the middle of the sample width)

Estimation of the critical load that can be carried out by the composite material requires definition of failure indicators. Such indicators could be based on strain or stress, thanks to Digimat, either defined on the composite or its constituents that are matrix or fibers. In Fig. 5 the stress results for Simulation 2 at different loads (marked by “x” in Fig. 3) superimposed with failure indicator result (elements with exceeded tensile strength are hidden) are presented. In this case failure indicator was defined based on the maximum allowable stress in fibers which is able to carry most of the load due to very high degree of fibers orientation. Applied failure indicator allowed prediction of the critical load with reasonable accuracy.

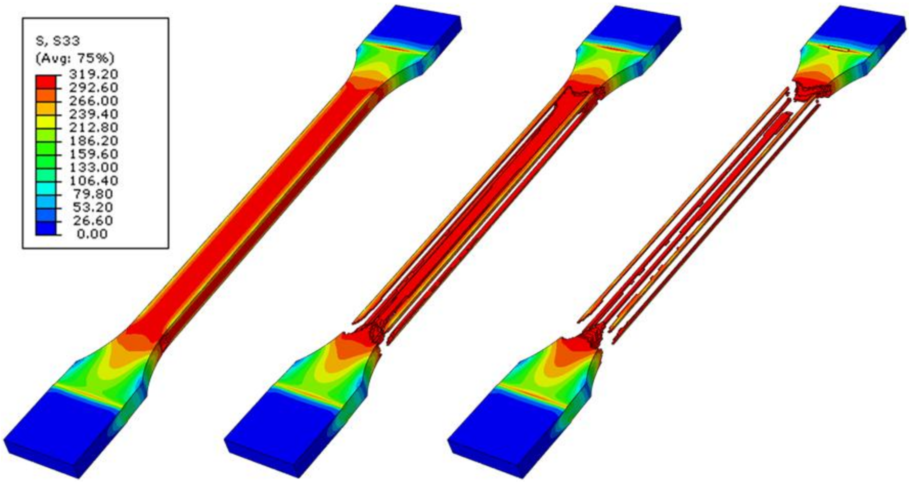


Fig. 5 Stress in ISO 527 sample at different load steps

## CONCLUSIONS

Thermoplastics reinforced with short fibers demonstrate anisotropic mechanical properties. Performed experimental measurements confirmed significant dependency of tensile modulus and strength on the direction of load. Samples machined transverse to flow direction failed at about 35% of the maximum load which can be carried by directly molded specimen. Therefore, prediction and optimization of mechanical performance cannot be realized without fibers orientation taken into account. Presented simulation approach, which incorporates injection molding simulation in the first stage, takes the fibers orientation into account. This approach provides more accurate prediction of mechanical behavior of analyzed part. However, one of the key factors influencing accuracy of mechanical simulation results is correct prediction of the fibers orientation. Selection of injection molding simulation software package must be done carefully. Applied failure indicator allowed prediction of the critical load for directly molded sample with reasonable accuracy. Verification of presented approach is ongoing and correlation between simulation and reality will be investigated for other types of samples as well as for complex geometries (real products).

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