# With Autodesk Advanced Material Exchange and Abaqus to precise results of structural FEM for fiber reinforced polymers

*Case study of a comprehensive approach to prove that coupling structural FEM and process analyses yields in very accurate results*


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Celje, Slovenia, 2016


***ABSTRACT***

*Fibre reinforced materials are an excellent alternative to light metals and sheet metal in the constant strive for reduction of mass for critically loaded components, such as eg. oil filter housings and engine brackets. However, with structural FEM classic material data fails as it doesn't include fibre orientation effects. Since latter cause substantial anisotropy in material, we must calculate on the safe side if we don't know the actual fibre orientation.*

## Introduction

At TECOS we've learned the need for precise FEM analyses of fibre reinforced materials long time ago. Due to such analyses being very complex their accuracy or correlation with experiments needs to be checked carefully. This paper presents thorough analysis of accuracy of precise structural analyses for fibre reinforced materials with the usage of Abaqus coupled with leading injection moulding analysis software package Autodesk Simulation Moldflow Insight. The concerned specimen is shown on Fig 1, material PA6 Durethan BKV 30 H2.0 with 30% glass fibres was used. The specimen was injected from two different locations (gate A – longitudinal, gate B – perpendicular). Consequently two different fibre orientations were introduced into otherwise identical geometry of the specimens.

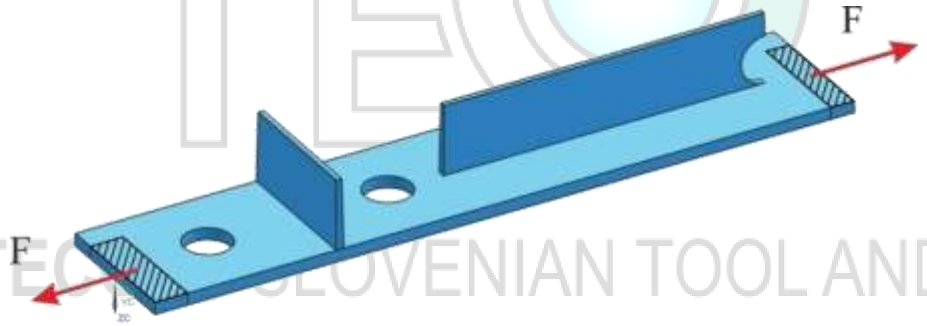


**Fig 1:** Specimen made from reinforced thermoplastic material **PA6 Durethan BKV 30 H2.0.**

The prerequisite for precise analyses is knowing the correct fibre orientation which is produced with injection moulding simulation (Autodesk Moldflow). It is essential that market leading product is used for the latter, furthermore the compatibility with Abaqus is also a must. Fig 2 shows prediction of warpage for both gate locations.

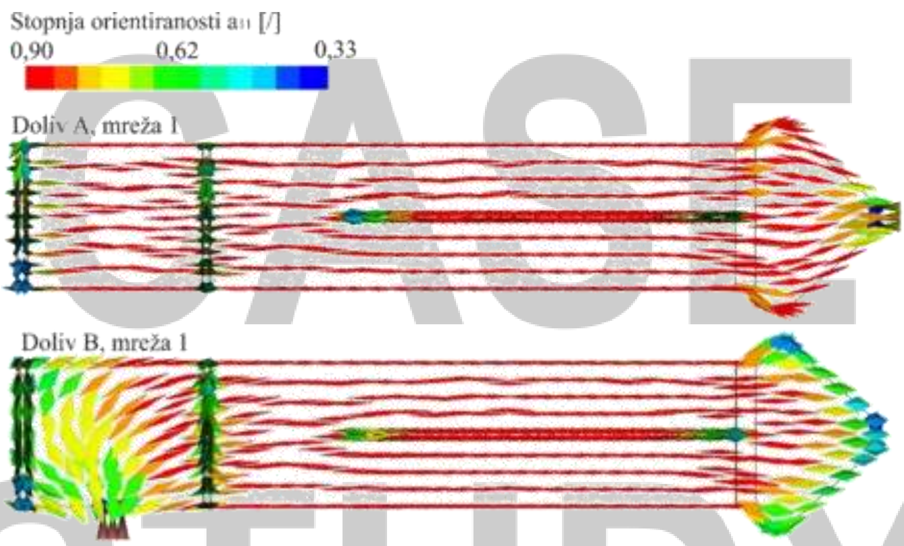


**Fig 2:** Fibre orientation in the specimens for different gate locations

## Methodology Used

The primary result is the highest load the specimen can withstand. For obtaining these 6 different methods were used:

1. **Analytical approach (linear, without fibers orientation):**
   Tensile strength was calculated analytically in the critical section with assumption that the probability of fibres being oriented perpendiculary to the loads is high (critical spots, often used in real life – material data in perpendicular direction without considering the fibre orientation)
   This is the easiest and fastest method, but applicable only to simple geometries which is usually not the case. This method yields in extremely conservative results when material data in perpendicular direction is used.

2. **Isotropic materially linear analysis (Abaqus, linear, without fibers orientation):**
   Tensile strength was calculated numerically. Classical isotropic linear material model was used together with the assumption that the probability of fibres being oriented perpendiculary to the loads is high (critical spots, often used in real life – material data in perpendicular direction without considering the fibre orientation).
   This is a numerical approach which yields in fast and simple check of product strength for complex geometries. This method again yields in extremely conservative results when material data in perpendicular direction is used.

3. **Isotropic material non-linear analysis (Abaqus, non-linear, without fibers orientation):**
   This approach is the same as the previous one with the difference that materially non-linear data was used. The method performs better with large deflections and materials that behave distinctively non-linear (lower percentage of fibre reinforcements). But nevertheless this method again yields in extremely conservative results when material data in perpendicular direction is used.

4. **Analysis with the consideration of linear orthotropic material data (Abaqus+Moldflow, linear, with fibre orientation):**
   Tensile strength was calculated numerically. Fibre orientation predicted by injection moulding simulation was used and orthotropic linear-elastic material model was used (linear mateiral data in all orthogonal directions).
   This is an advanced numerical method which considers the true fibre orientation. Such method takes into account the influence of technological process on the mechanical properties of the specimens and yields in more precise results in case of small deflections or materials that do not behave distinctively non-linear.

5. **Analysis with the consideration of non-linear orthotropic material data (Abaqus+Moldflow+Advanced Material Exchange, non-linear, with fibers orientation):**
   The approach is similar to the previous one with the difference that non-linear material data is mapped to idealised finite element mesh (Autodesk Advanced Material Exchange).
   Orthotropic elasto-plastic material model was used together with the failure model for composite material (non-linear material data in all orthogonal directions). For the prediction of fibre orientation injection moulding simulation was used (Autodesk Moldflow).

6. **Experimental approach (tensile tests):**
   Tensile testing was performed on several specimens. Real strength of specimens was obtained (Figs 5 and 6).

## Results

**Table 1:** Results of all approaches; it can be clearly seen that the approach with coupled Abaqus FEM and injection moulding analyses yield in by far the most precise results

| No | Method | Critical Loada [N] | | Error | |
|---|---|---|---|---|---|
| | | **Gate A** | **Gate B** | **Gate A** | **Gate B** |
| 1 | Analytical approach | **2772** | | 56,0% | 41,0% |
| 2 | Isotropic materially linear analysis (Abaqus-linear) | **2801** | | 54,4% | 39,5% |
| 3 | Isotropic materially non-linear analysis (Abaqus-non-linear) | **3074** | | 40,7% | 27,1% |
| 4 | Analysis with the consideration of linear orthotropic material data (Abaqus+Moldflow-linear) | **3465** | **3118** | 24,8% | 25,3% |
| 5 | Analysis with the consideration of non-linear orthotropic material data (Abaqus+Moldflow+Advanced Material Exchange-non-linear) | **4275** | **3871** | 1,1% | 1,0% |
| 6 | Experimental approach | **4324** | **3908** | / | / |

For a better illustration a graphical representation is shown in Fig 3. Red lines indicate experimental data. The excellent correlation of method 5, i.e. coupled FEM and injection moulding analysis, and experimental data is clearly observed.

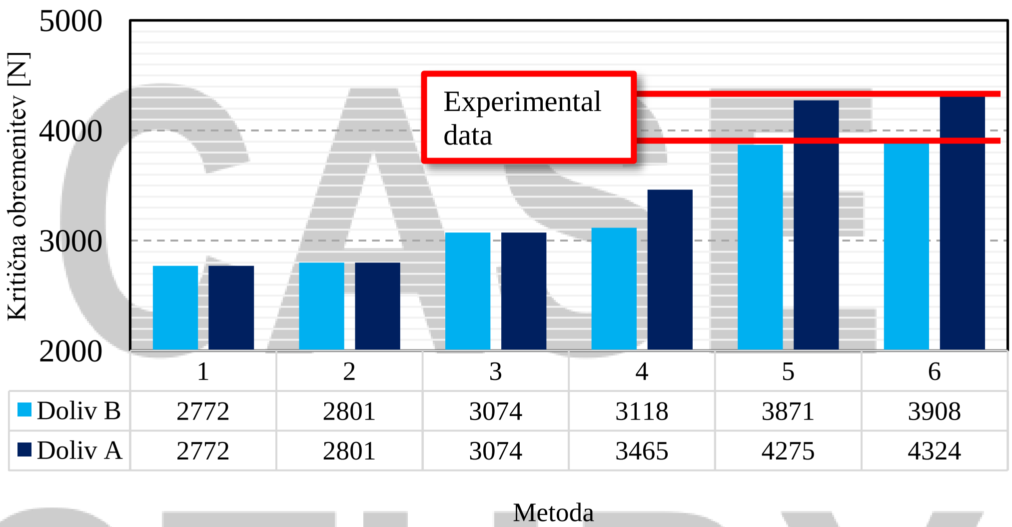


**Fig 3**: Graphical representation of results for all used approaches; red lines represent experimental data (method 6) – a great correlation of method 5 and experimental data is clearly visible

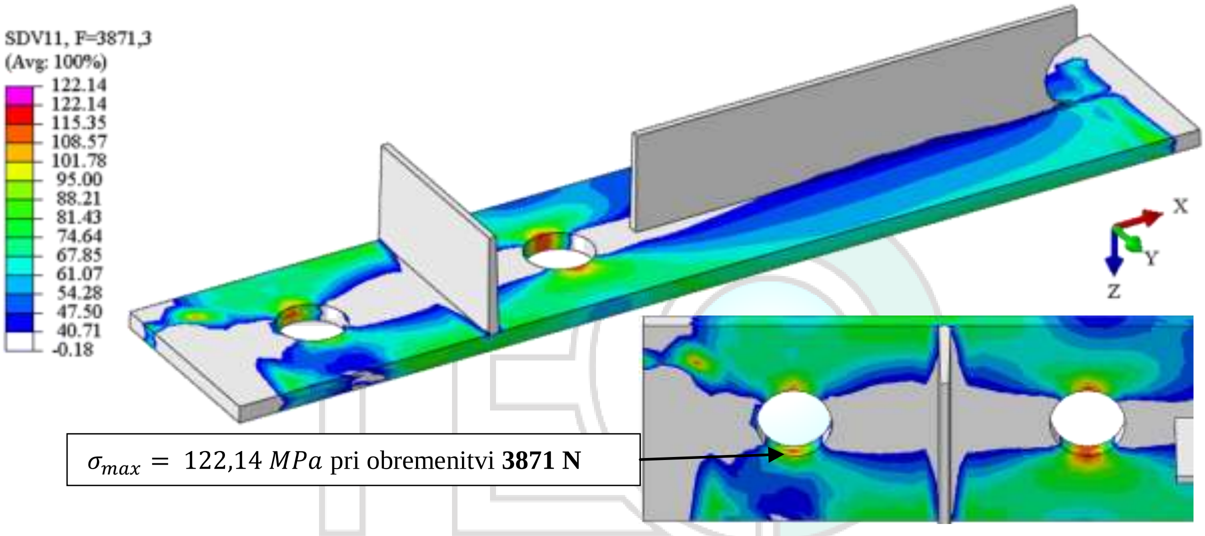


**Fig 4:** Equivalent tensile stress distribution of the composite matrix in [MPa] for the specimen injected from the side (gate B). Analysis with consideration of non-linear orthotropic material data was performed.

Fig 5: Tensile strength testing

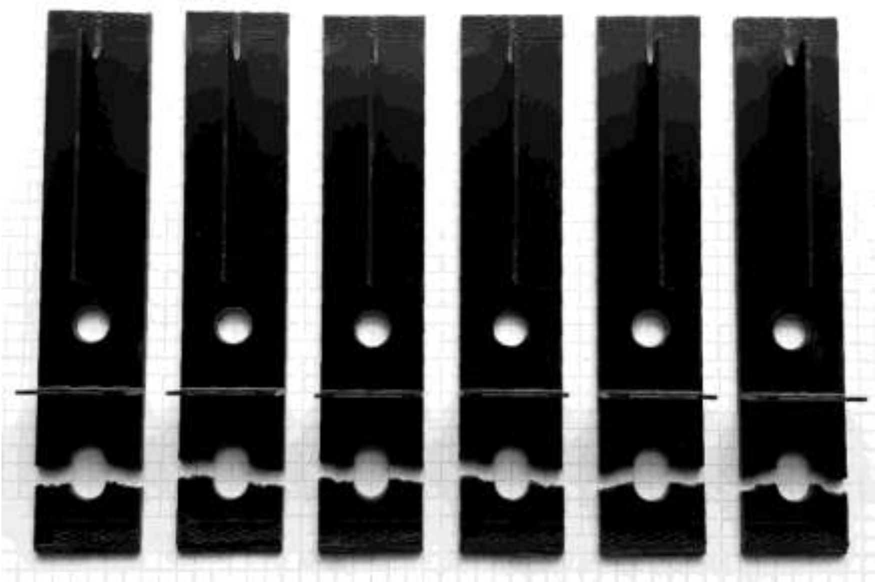

Fig 6: Tensile test specimens



## Conclusions

Computer aided analyses of fibre reinforced materials with simplified material models where orthotropy and material non-linearity are neglected while being on the conservative side yield not very precise results. They can be used for a fast evaluation of product strength in the starting phase of product development. On the other side such analyses are not very useful when we want to develop optimised products with the lowest possible material use at the requested strength. To illustrate this, this paper shows errors in the range from 25 to 50% and for some approaches even more.

To summarise:

- it can be concluded that taking the orthotropy or fibre orientation into account significantly raises the accuracy of numerical resultsn **(Abaqus+Moldflow+Advanced Material Exchange)**.
- such analyses also enable the consideration of the effect of different mechanical properties due to different gate locations
- the paper has prooved that the concerned method gives very accurate results and can yield in optimised products with the best ratio between material usage and strength .