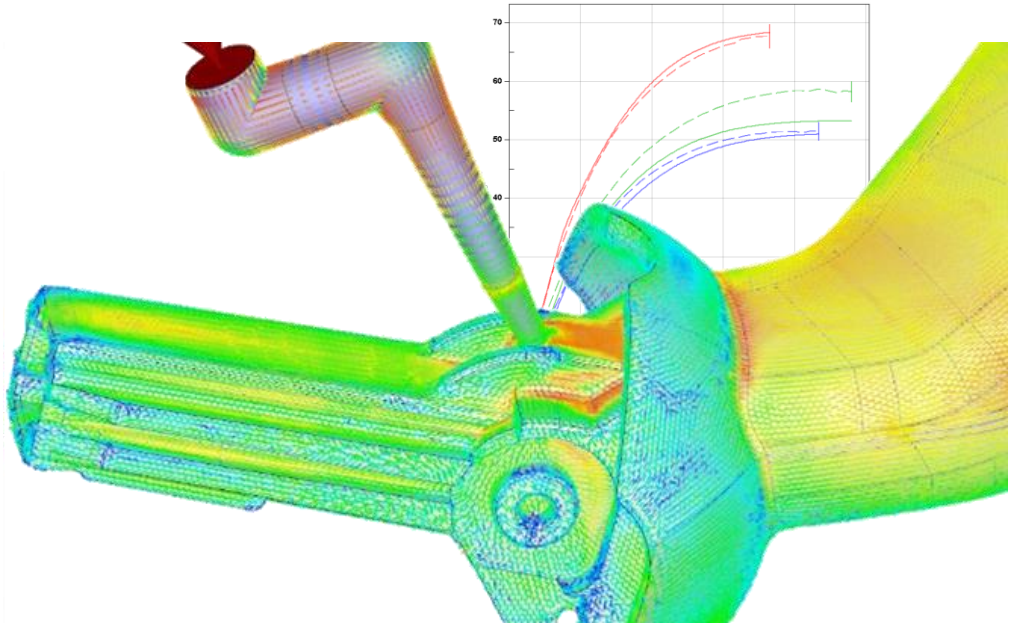
Hello,
My name is Tomas Ruzicka and as a member of the Kostal simulation team
I would like to share with you our work on simulations respecting glass fibers in our products with some examples...

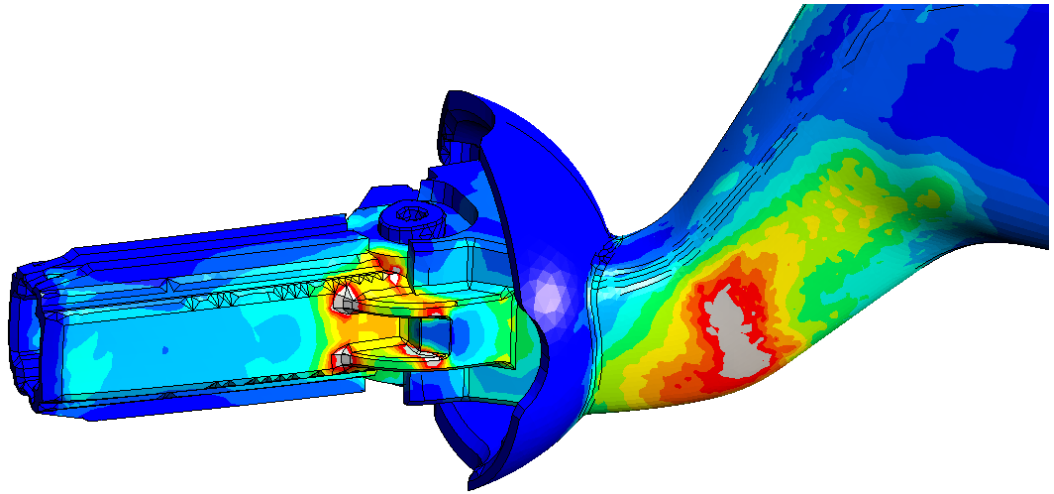
Hexagon user conference 2024
Kostal
Accounting for anisotropy in strength calculations of plastic parts using the Digimat platform (Commented version)

Tomas Ruzicka

Kostal / Technology development dept.

18.06.2024





Content

- **Simulation of glass fiber reinforced parts**
  - **Company introduction**
  - **Anisotropy meaning**
    - Isotropic vs Anisotropic material definition
  - **Stiffness analyses**
    - Various simulation approaches
    - Material models
  - **Failure prediction**
    - Failure of parts with strong anisotropic effect

I'm here for the first time so I would like to first introduce our company.
Then I'll say few words to theory what anisotropy is.
Then to show its application on stiffness analysis
and finally we'll take a look at failure prediction of these Glass Fiber reinforced parts.

Kostal company introduction

In Lüdenscheid since 1912 – Leopold Košťál
44 locations worldwide
Over 17 000 employees worldwide
Prague – Kostal engineering (two divisions, ~200 employees)

A little about us… Kostal is a family company founded in Germany more than 100 years ago. In the Czech Rep. we have had subsidiaries for about 30 years. The one I'm working in is now located in Prague, where we moved a few years ago.

Our locations

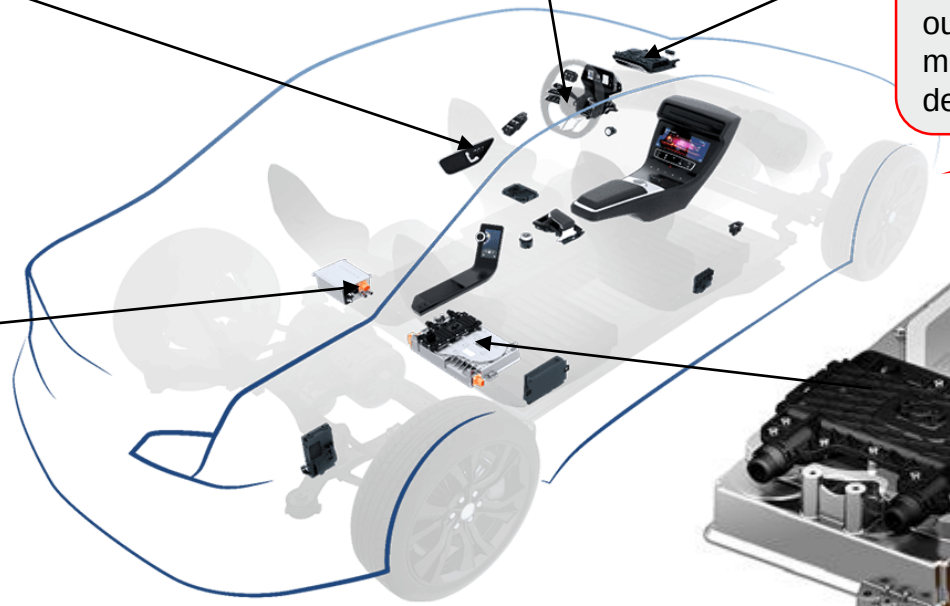
Our partners

Steering Column Modules

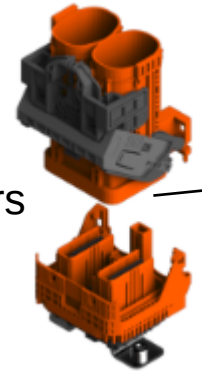
Rain/light sensors
Driver assistance camera

Switch panels

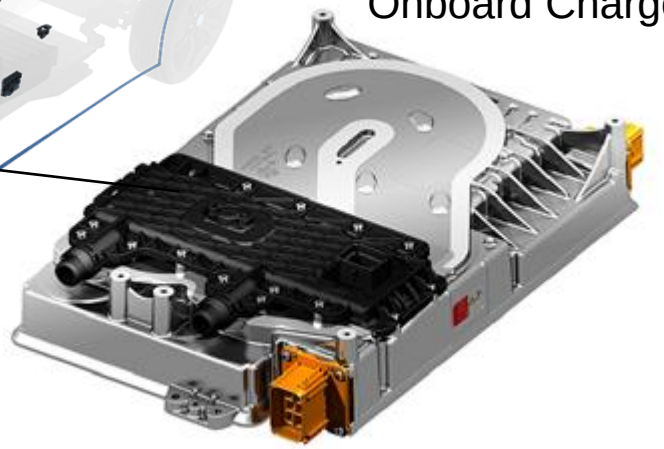
Talking about the portfolio... together with other products like solar inverters, industrial electronics and so on, automotive components are our core business. The ones I'm dealing with are steering column modules. In the past, some people asked me, "What are you still developing there...these are just levers!"



Connectors



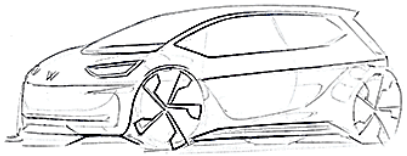
Onboard Chargers



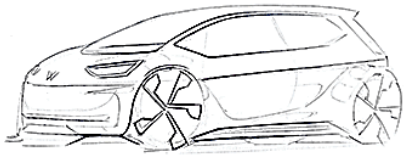
Non-automotive:
Solar inverters,
industrial electronics…

Switches in cars then……

Switches in cars then……and now

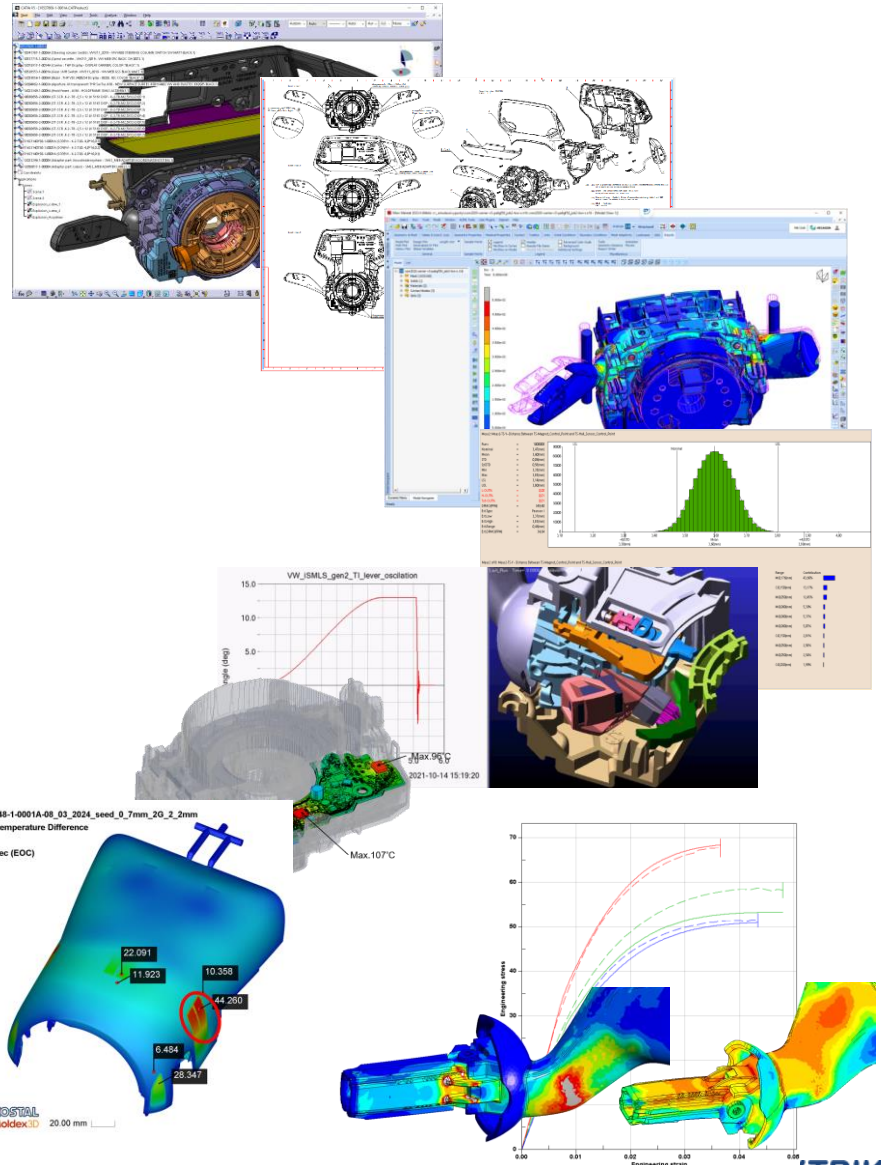


Switches in cars then……and now



After the initial CAD phase, the structural analysis begins. In our case with MARC/Mentat. Then 3D tolerance study, kinematics and dynamics in ADAMS, some CFD in Cradle, filling study and also the analysis I want to talk about today.... Anisotropic simulations combining both, filling study and structural analysis...

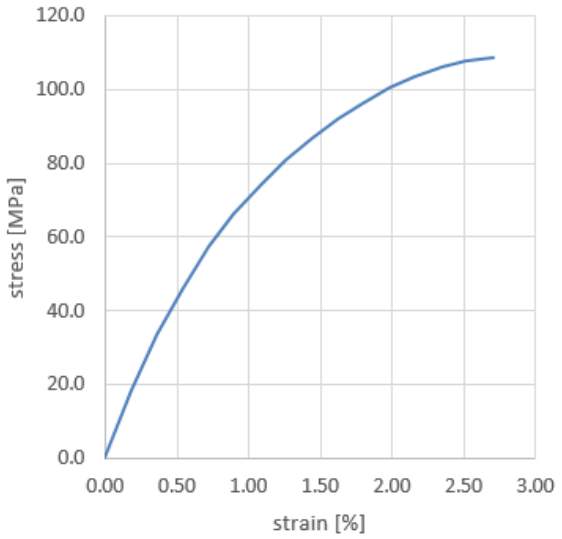
… and some of the tools we use now in development



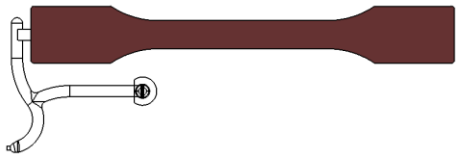
Content

- **Simulation of glass fiber reinforced parts**
  - Company introduction
  - **Anisotropy meaning**
    - Isotropic vs Anisotropic material definition
  - Stiffness analyses
    - Various simulation approaches
    - Material models
  - Failure prediction
    - Failure of parts with strong anisotropic effect

Isotropic properties



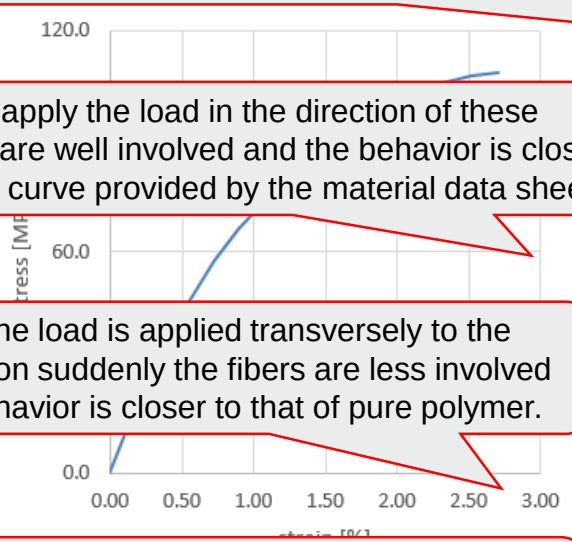
Running the FEM simulation we have to specify material model as a one of basic inputs.
Standard / so called isotropic / approach means to use Stress-strain dependency given by one curve obtained from material tensile test or datasheet.
In case of unreinforced homogenous materials like POM, PBT it's all we need.



Directly injected test specimen

Isotropic vs. Anisotropic material definition

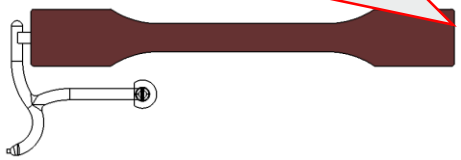
By adding glass fibers to polymer we create a composite of soft matrix like PA or PP and glass filler with times higher stiffness.
To imagine…glass is about 40 times more stiff then Polypropylen.



Then If we apply the load in the direction of these fibers they are well involved and the behavior is close to the ideal curve provided by the material data sheet.

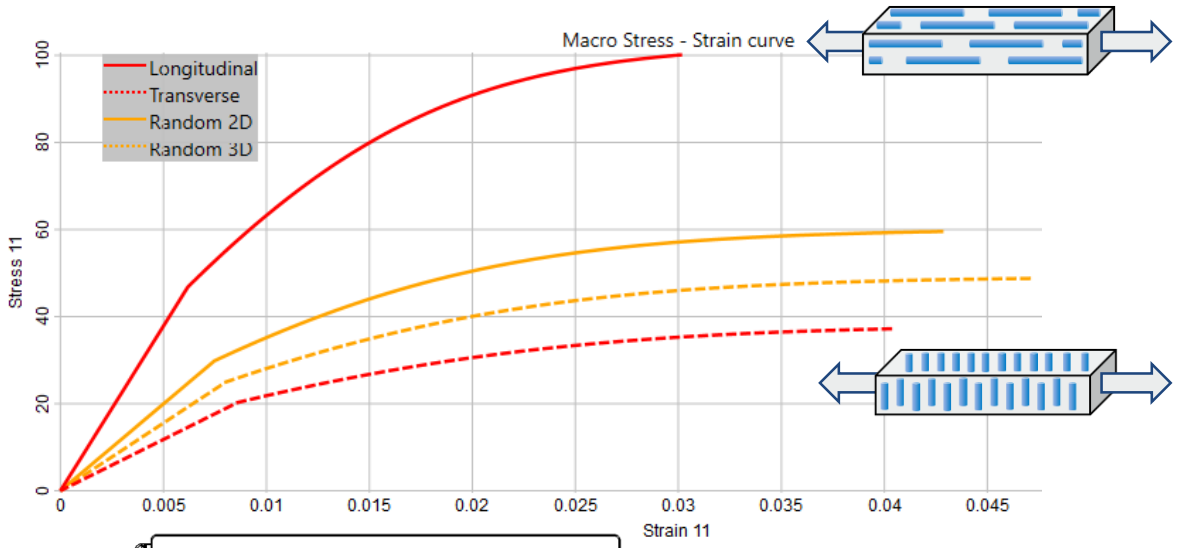
But when the load is applied transversely to the flow direction suddenly the fibers are less involved and the behavior is closer to that of pure polymer.

Understanding the fiber orientation in the part and assigning a corresponding mechanical properties to each element is the goal of anisotropic analysis.



Directly injected test specimen

Anisotropic properties



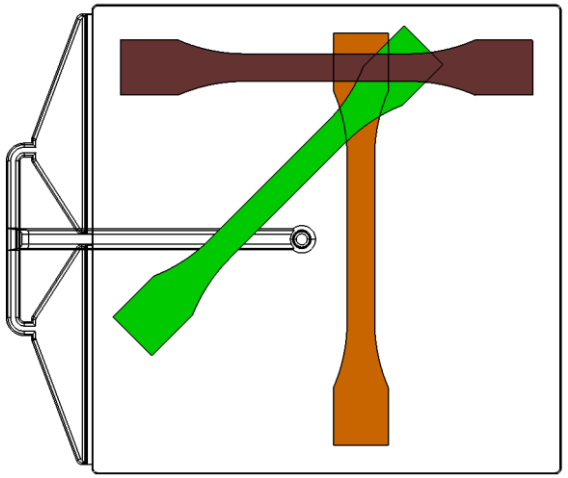


Plate for milled test specimens

Glass fibers in polymer matrix

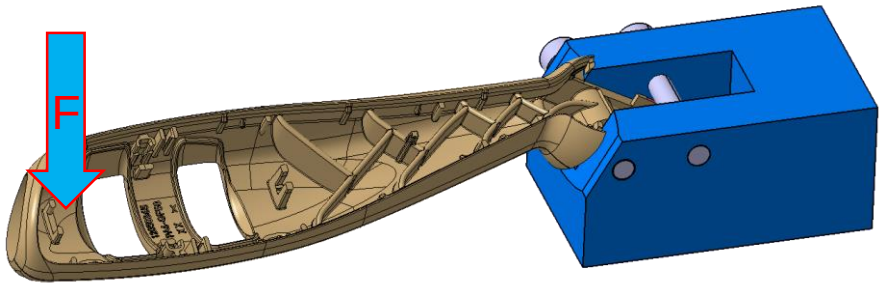
Content

- **Simulation of glass fiber reinforced parts**
  - Company introduction
  - Anisotropy meaning
    - Isotropic vs Anisotropic material definition
  - **Stiffness analyses**
    - Various simulation approaches
    - Material models
  - Failure prediction
    - Failure of parts with strong anisotropic effect

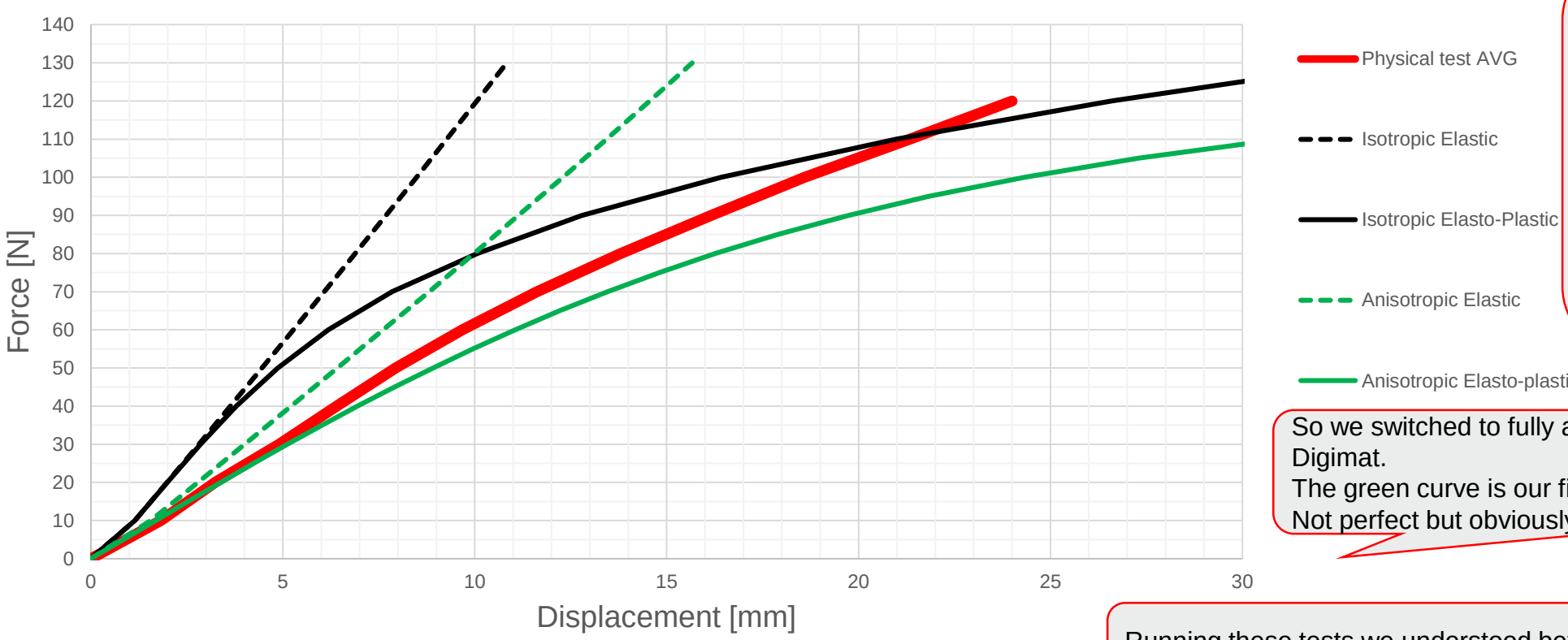
Our research into anisotropy began with a customer request for a narrow range between the minimum force to be withstood by lever misuse and the maximum force that would ensure the lever broke. Our thinking was that in order to accurately predict failure, we should first be sure about the stiffness...

Stiffness analysis of various simulation approaches

So we took the Lever, measured its response on the Zwick machine and compared the results with various simulation approaches



Red curve is the physical test result
The most basic is the linear elastic simulation which is used only for some rough analysis and you can do it directly in Catia.
In most cases we are using elasto-plastic material model based on one stress-strain curve
Both mentioned so far are not respecting glass fiber orientation.

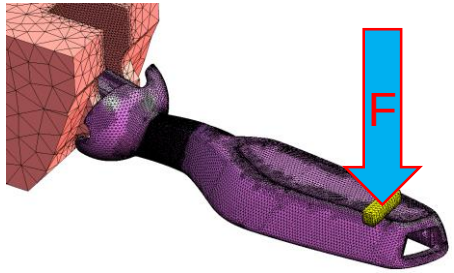


Then we started with anisotropy provided by module in Moldex3D software able to export mechanical properties based on filling simulation.
As we realized soon this model was elastic only so it was better only in initial area and for our purpose it was insufficient.
Plasticity is just something we have to respect.

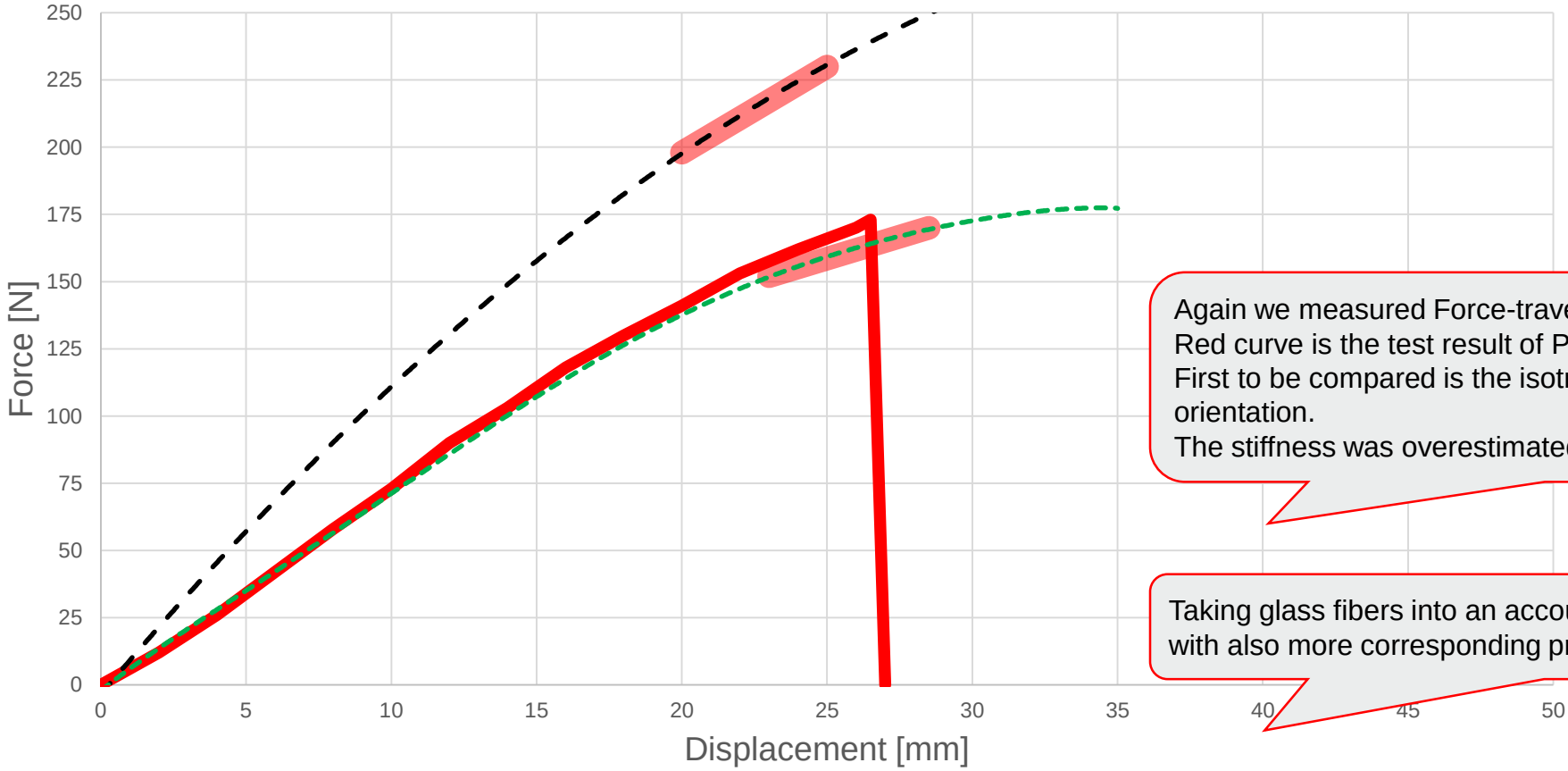
So we switched to fully anisotropic analysis software called Digimat.
The green curve is our first shot.
Not perfect but obviously it was a right direction.

Running these tests we understood better that conditioning (I mean humidity influence) and also the material model is something we have to focus on.

Stiffness analysis – Material models



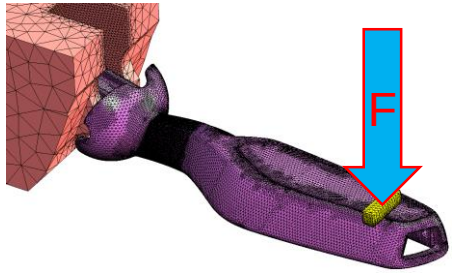
So for the next round of tests we selected a similar part but made from a material with a good available material model in Digimat database
And in parallel we decided to create our own material model for alternative material to validate also reverse engineering approach.



Again we measured Force-travel diagram of Lever breaking.
Red curve is the test result of PA6GF50 used in serial production.
First to be compared is the isotropic approach not considering fiber orientation.
The stiffness was overestimated and so was the predicted failure.

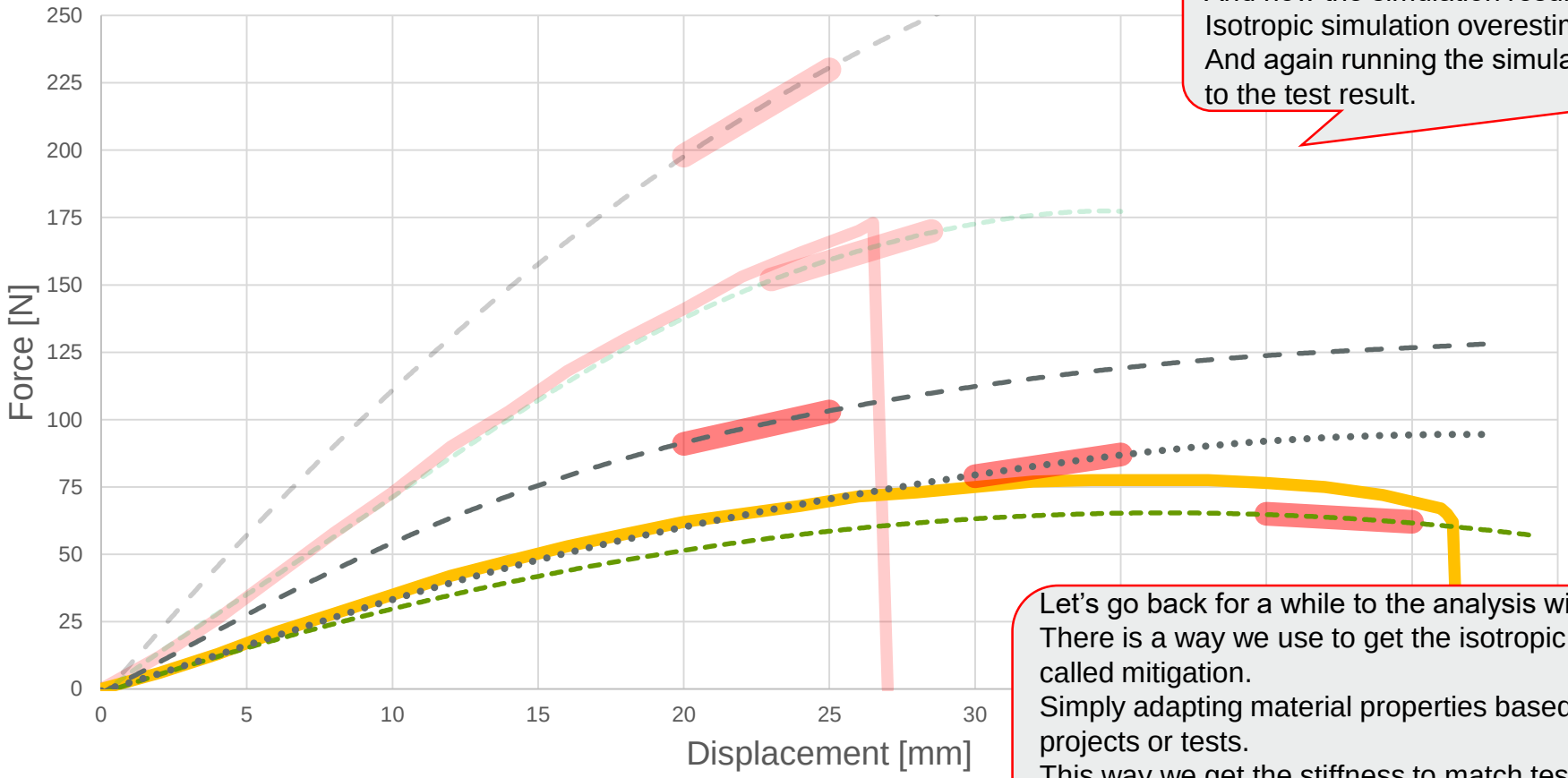
Taking glass fibers into an account stiffness was captured much better with also more corresponding predicted failure.

Stiffness analysis – Material models



As an alternative material for our reverse engineered material model we chose PPGF40 recyclate
Because it's used for a lot of parts and we didn't have a proper material model.

Yellow is the test result
And now the simulation results….
Isotropic simulation overestimates both, stiffness and failure, again.
And again running the simulation with glass fibers we've got both closer to the test result.



Let's go back for a while to the analysis without glass fibers taking into account…
There is a way we use to get the isotropic simulation closer to the reality and it is so called mitigation.
Simply adapting material properties based on already known results from previous projects or tests.
This way we get the stiffness to match test pretty well and also the failure force is almost perfect
This puts the usual isotropic simulation in a good position in many cases.

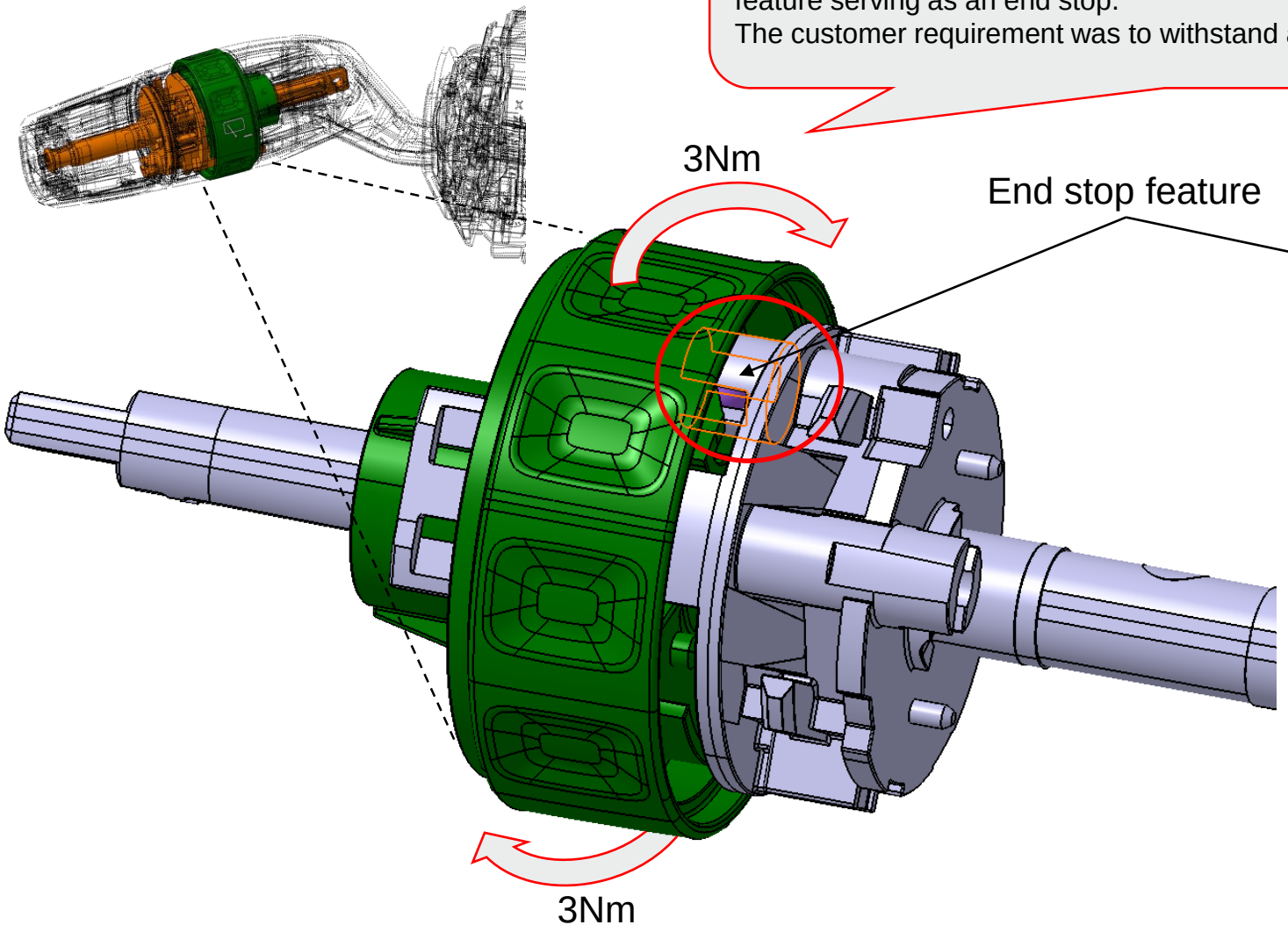
Content

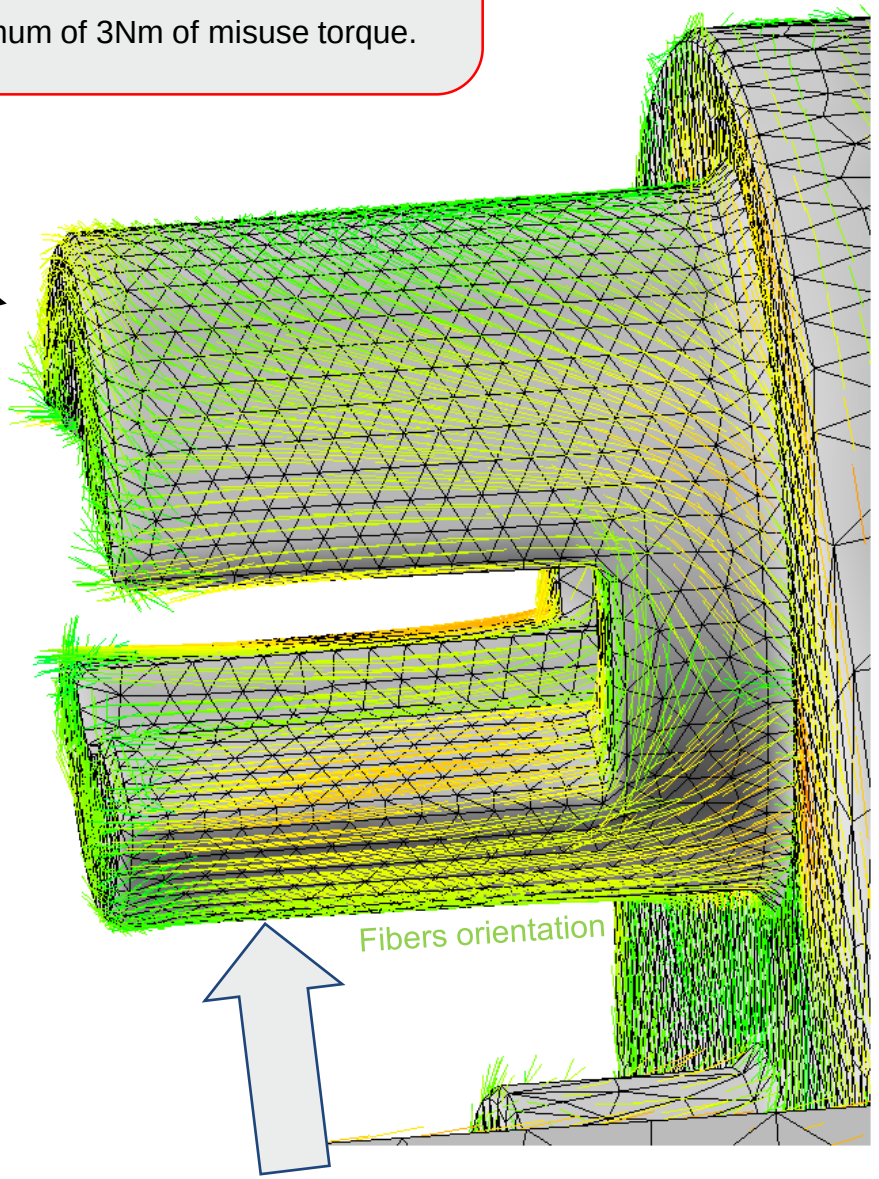
- **Simulation of glass fiber reinforced parts**
  - Company introduction
  - Anisotropy meaning
    - Isotropic vs Anisotropic material definition
  - Stiffness analyses
    - Various simulation approaches
    - Material models
  - **Failure prediction**
    - Failure of parts with strong anisotropic effect

…But where even this approach fails compared to fiber-respecting simulation are the cases with strong anisotropic effect…

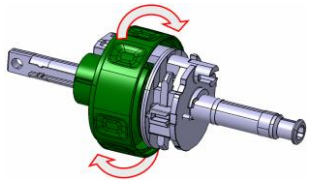
Failure prediction

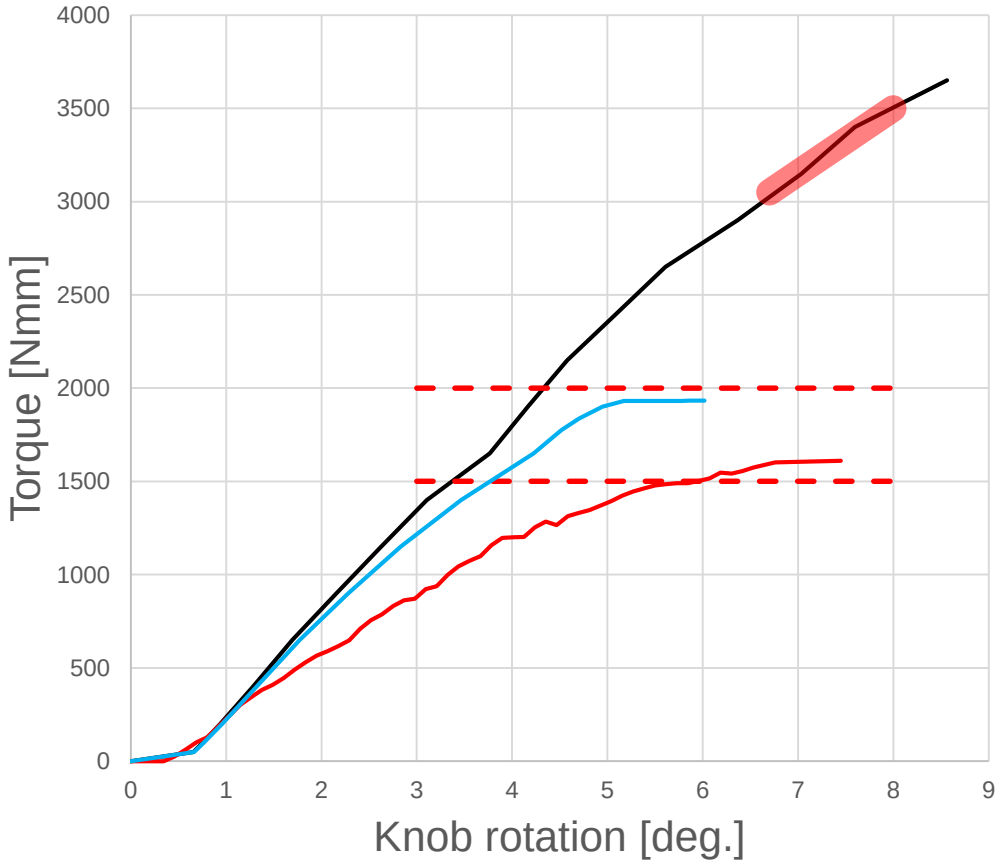
…by other words if the load is applied transversely to the fiber orientation.
Typical examples are the end stops for rotary rings.
What we see on the picture is the rotary ring assembled on carrier with this kind of feature serving as an end stop.
The customer requirement was to withstand a minimum of 3Nm of misuse torque.





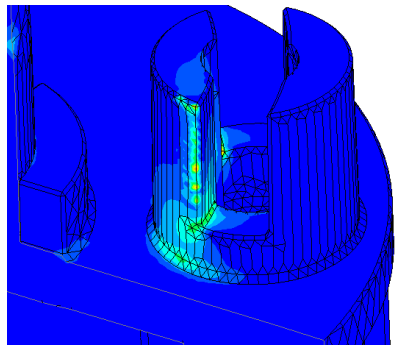
Failure prediction



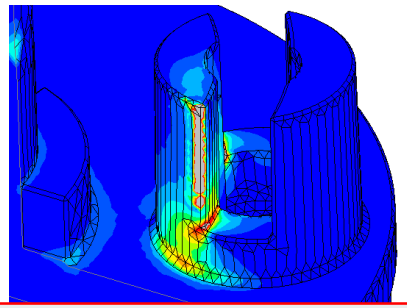


Isotropic
(Mixed cond. with mitigation)

2Nm

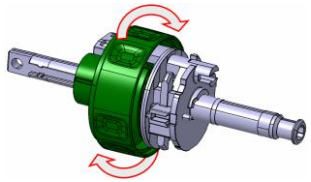


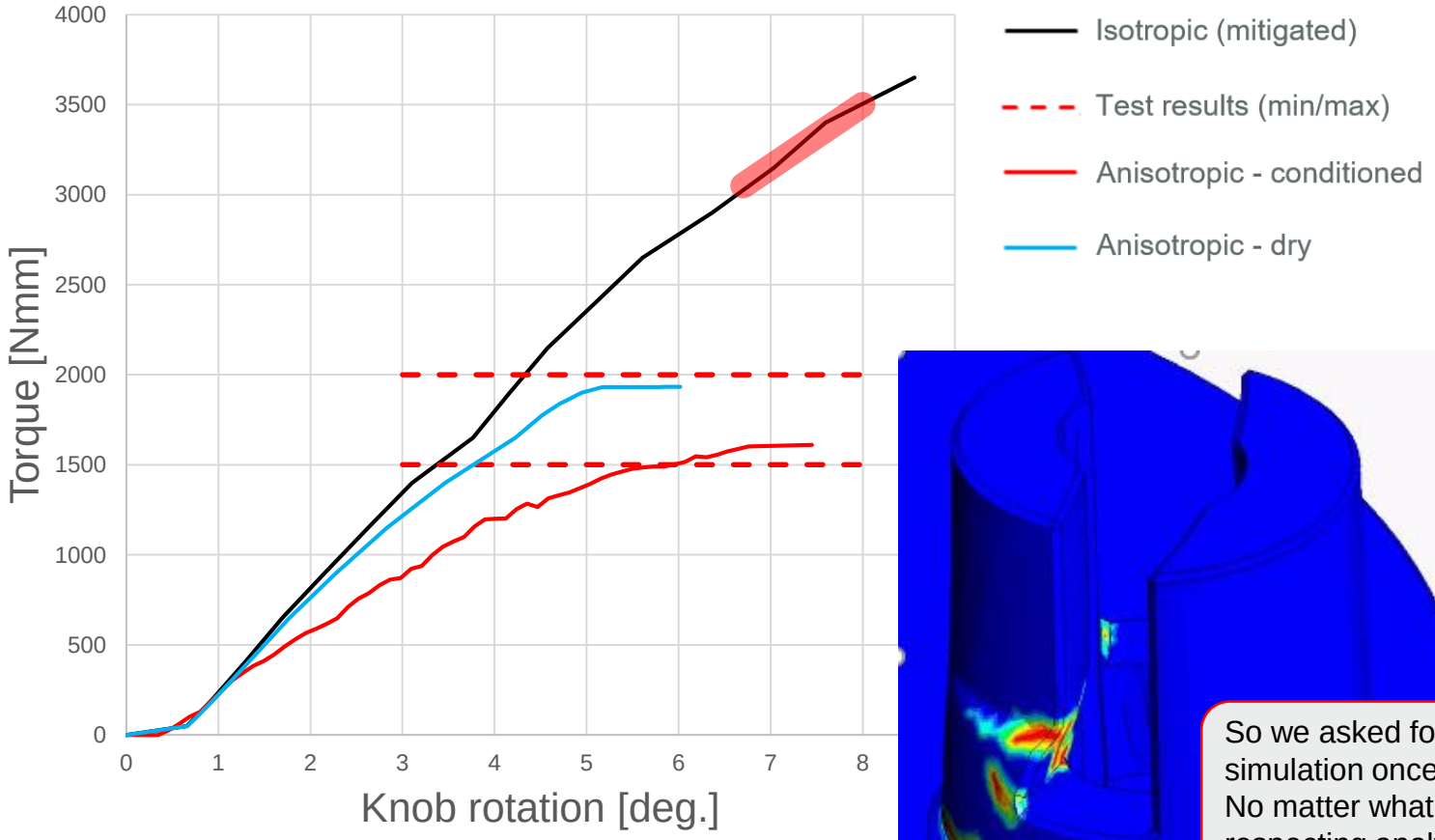
3Nm



So the simulation was done with all the ammunition we have without knowing the fiber orientation.
I mean the mitigation I mentioned and also with the humidity effect.
The result was that the first failure should be over 3Nm so It sounded good enough
Unfortunately, product validation a few months later told a different story....
At half of this requirement the deformation occurred and at 2Nm the end stop was completely broken.

Failure prediction

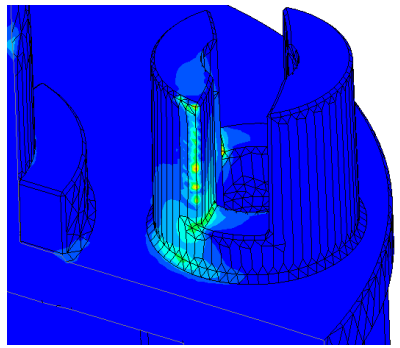




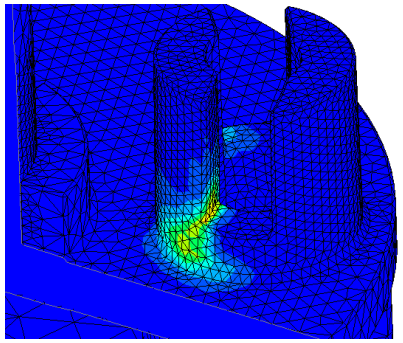
Isotropic
(Mixed cond. with mitigation)

Anisotropic
(dry)

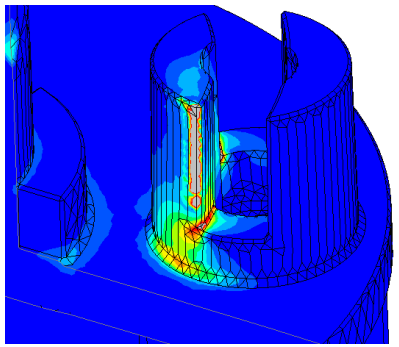
2Nm



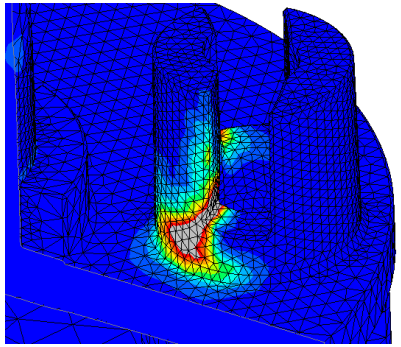
1.5Nm



3Nm



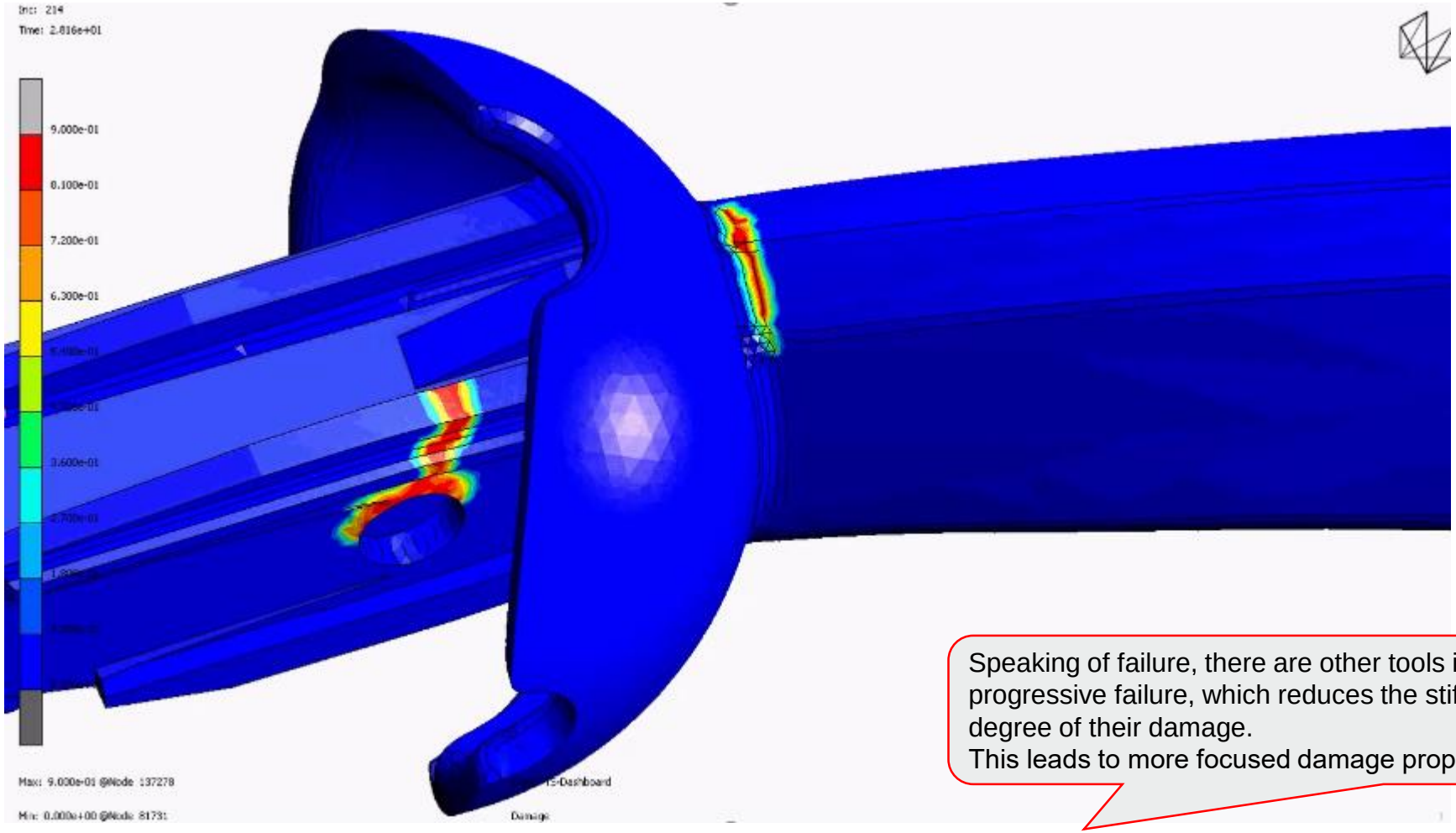
1.9Nm



So we asked for the fiber orientation from the moldflow results and ran the simulation once again, this time in an anisotropic way.
No matter what material model we choose, conditioned or dry, with the glass fiber respecting analysis the failure was predicted well within the test results.

Failure prediction

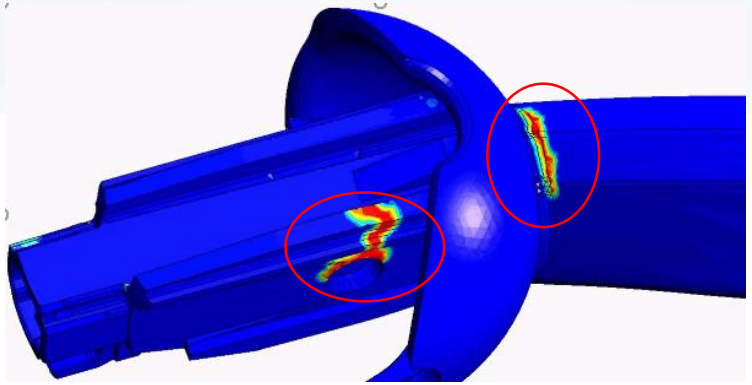
Progressive failure



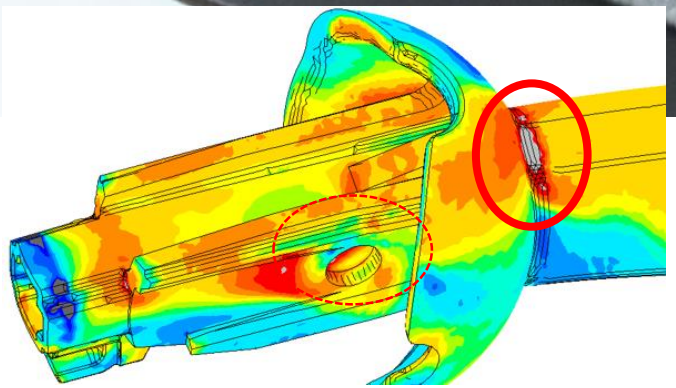
Speaking of failure, there are other tools in Digimat to help us predict it, such as the progressive failure, which reduces the stiffness of certain elements based on the degree of their damage.
This leads to more focused damage propagation as shown here…

Failure prediction

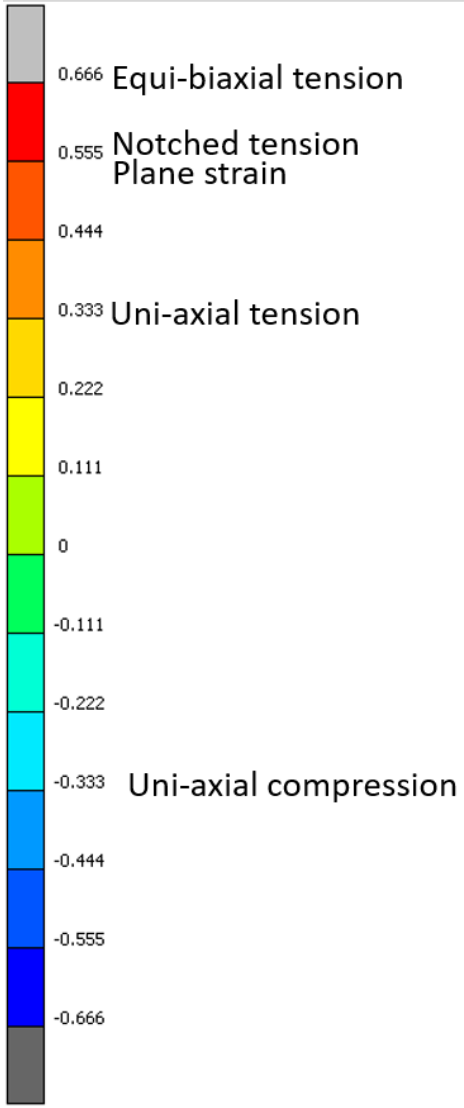
...or stress triaxiality analysis, which helps us to distinguish failure criticality in certain areas.
But time is running out.....so I'd like to summarise what we've experienced with this type of simulation...



Damage/failure



Stress triaxiality



Conclusion

From what we have done so far we see anisotropy as a good improvement in simulation accuracy.
With more corresponding deformation leading to a better failure prediction.

But on the other hand It is more complicated and therefore more time consuming analysis.
Also the availability of material models is limited compared to isotropic simulation and creating our own models means another time to be spent on.

Pros

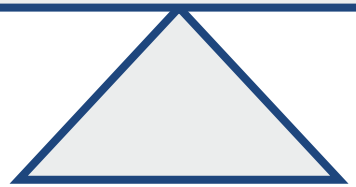
Simulation accuracy

Better failure prediction

Cons

More complicated and time consuming

Material models availability



Currently we use Digimat mainly for advanced analysis of critical parts
(Approximately 20%-30% of the structural simulations in our department are performed using this fiber respecting software)

Current usage: Advanced analysis of critical parts

Thermally dependent parts

Next steps: To create and validate material models for missing grades used by Kostal

So I hope there will be an opportunity for us to exchange some insights and experiences.

Thanks for your attention and in case of any question please let me know.

THANK YOU

Tomas Ruzicka
T.Ruzicka@kostal.com