THERMOFIL HP® – Innovative solutions for Light weighting using engineering glass fiber reinforced PP

N. SCHLUTIG, SUMIKA Polymer Compounds France, SAINT MARTIN de CRAU

Abstract

Automotive light-weighting is a long-term trend because it reduces emissions and fuel consumption, and it increases vehicle range and performance.

In anticipation of this trend, Sumika Polymer Compounds Ltd. developed THERMOFIL® HP high performance chemically coupled glass-fibre reinforced polypropylene grades approximately 15 years ago, and they continue to create new and improved grades.

To facilitate light-weight solutions with THERMOFIL ® HP, Sumika Polymer Compounds Ltd. partnered with Moldex® 3D, a premier provider of Plastic Injection Molding Software, Hexagon e-Xstream Engineering a leader in integrated computational material engineering (DIGIMAT® Data Management System) and Hexagon MSC Software (MARC® a powerful nonlinear finite element analysis solution).

This presentation compares predicted part performance to actual part performance for a brake pedal and pedal support.

First, some technical background behind DIGIMAT® digital material cards, including how they how they are created and validated, will be presented.

Then, the usage of a DIGIMAT® Digital Material Card to perform a Moldex® 3D mold filling simulation and a MARC® Finite Element Analysis to optimize the designs & predict the performance of a brake pedal and pedal support will be presented.

Finally, the predicted performance will be compared with actual performance to validate the predictive model.

When used together, THERMOFIL HP®, DIGIMAT digital material cards, Moldex® 3D injection molding filling analysis and Marc® non-linear anisotropic finite element analysis enables accurate design optimization and predictive engineering to reduce weight without sacrificing part performance.

Keywords

High performance Glass fibre reinforced PP Vs Standard Glass fibre reinforced PP. How THERMOFIL HP® range is superior (physical properties, etc…); HP GFPP Vs engineering thermoplastics; HP GFPP as a real cost saving light weight solutions. How THERMOFIL HP® material card will predict with a good accuracy the behaviour of complex part in automotive industry.

1. Introduction

Considering the current context of the automotive market which drives to reduce continuously CO_2 emission of cars as describe in the Policy update of international council on clean transportation (see figure (1)), automotive industry must be innovative in different domains like in engine & transmission design, hybridization of vehicles, vehicle electrification, aerodynamics but also in lighter weight of vehicles.

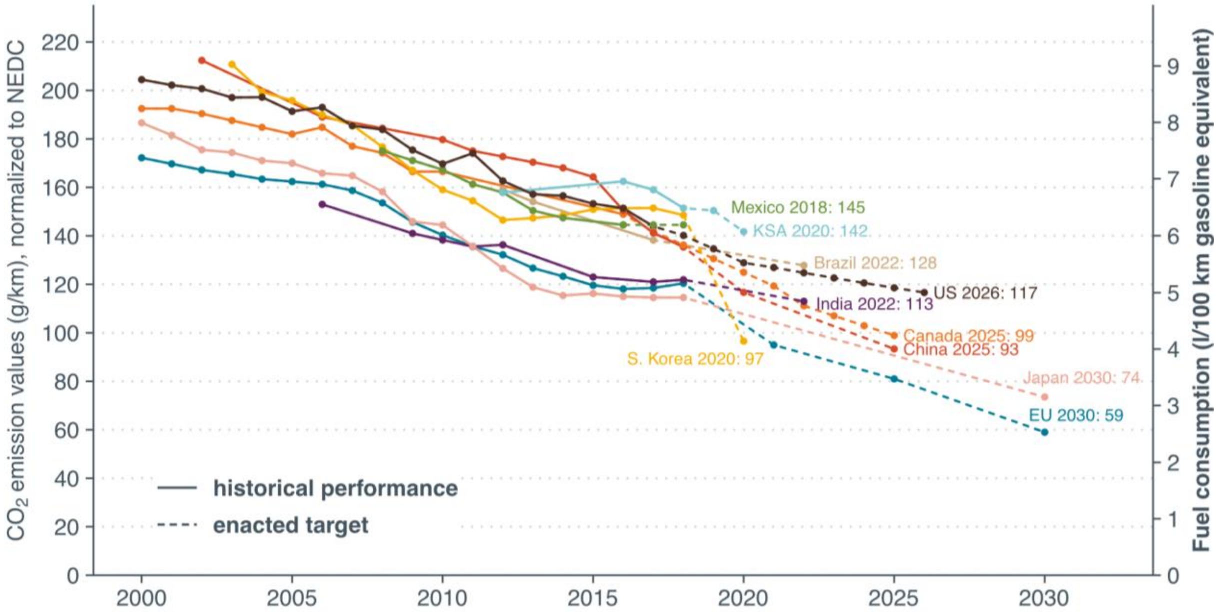


Figure 1-C02 emission target values

In that context of vehicles' weight reduction SUMIKA POLYMER COMPOUNDS innovate in this direction since more than 15 years. Latest evolution of our range THERMOFIL HP® allows us to obtain a standard of lightening on automotive parts without compromise performances. Furthermore, this innovation is available worldwide which is compliant with automotive market while keeping local specificity.

Moreover, the latest development in non-linear anisotropic approach combines with THERMOFIL HP® material card allow to predict with a very good accuracy behaviour of complex parts which unlock new opportunity and applications.

2. Customer challenges

To meet the target in terms of weight and sustainability, OEM request to propose an alternative to PA6-GF30 and PA6-GF50 to pedal box and brake pedal using metal insert (see figure (2)).

Figure 2- Pedal box and Brake pedal

As automotive market always looking for high level of performances and lightweight to achieve CO_2 emissions target, our THERMOFIL HP® range is well positioning in alternative lightweight solutions against traditional engineering plastics.

SUMIKA Europe have been propose some alternative has shown in the table [1].

Items	Method	Unit	PA6-GF30		THERMOFIL HP F611X	PA6-GF50		THERMOFIL HP F911X
			dry	wet		dry	wet	
Density	ISO 1183	g/cm^3	1,35		1,12	1,57		1,34
Ash content	ISO 3451	%	30		30	50		50
Humidity absorption	ISO 62	%	0,95		NA	1,2		NA
Tensile strength	ISO 527	MPa	150	100	114	225	160	142
Tensile elongation	ISO 527	%	3	4	3	3	5	2,7
Tensile modulus	ISO 527	MPa	8500	6200	7700	16500	10800	13000
Flexural modulus	ISO 178	MPa	8600	5500	6500	13500	9500	11200
Flexural strength	ISO 178	MPa	270	180	150	340	230	191
CHARPY Impact unnotched	ISO 179/1eU	KJ/m^2	95	110	58	95	100	58
IZOD impact	ISO 180	KJ/m^2	14	24	12	20	25	16

Table 1- THERMOFIL HP® comparison to PA-GF

The other challenge was also to check the feasibility of those part in PP-GF by minimize the prototype phase to address to OEM request to achieve development quicker, safer, and accurate.

3. SUMIKA solutions in CAE

3.1 SUMIKA Theory Background

SUMIKA use Non-linear anisotropic approach to ensure a high level of accuracy in the results obtains. To allow such results, a deep analysis in characterization and Reverse engineering has been made. The study consists in mould plates and cut some coupon (test bars) in different Glass fibre orientation (see fig (3)).

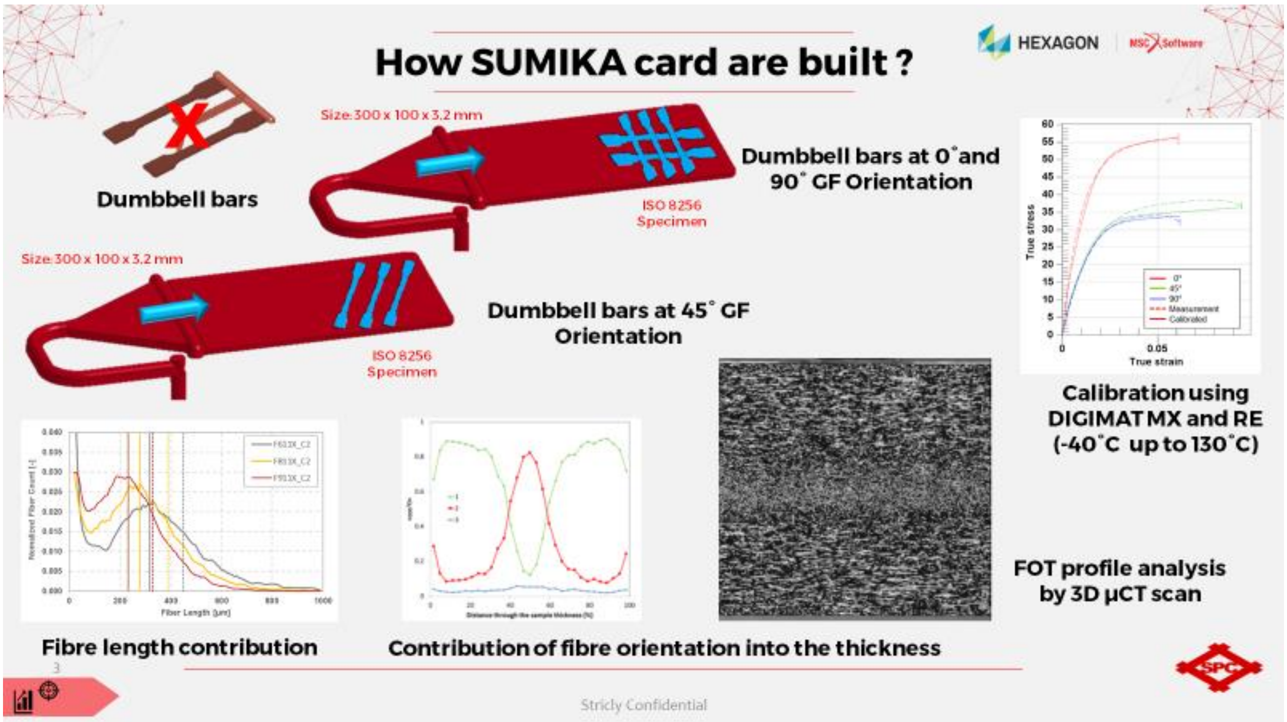


Figure 3-Coupon in different glass fibre orientation

Once test bars are prepared, several characterizations should be made as standard tensile measurement, high speed tensile measurement, Creep, fatigue, and CT scan measurement as well.

Later what we call "calibration" of all card has been made using Reverse engineering technology using different step.

Step one consists into define skeleton model by find the Elasto-Plastic (EP) model coming from the matrix and the Elastic (E) model coming from glass fibre. This also used CT scan to define multi-layer microstructure and aspect ratio as well. To perform such study, we used a two-step calibration based on micromechanics and mean-field homogenization theory to compute anisotropic properties of fibre reinforced thermoplastic [2]. We used in this case Mori-Tanaka model [3] and Pseudo-grain Voigt model [4] in second step (see fig (4))

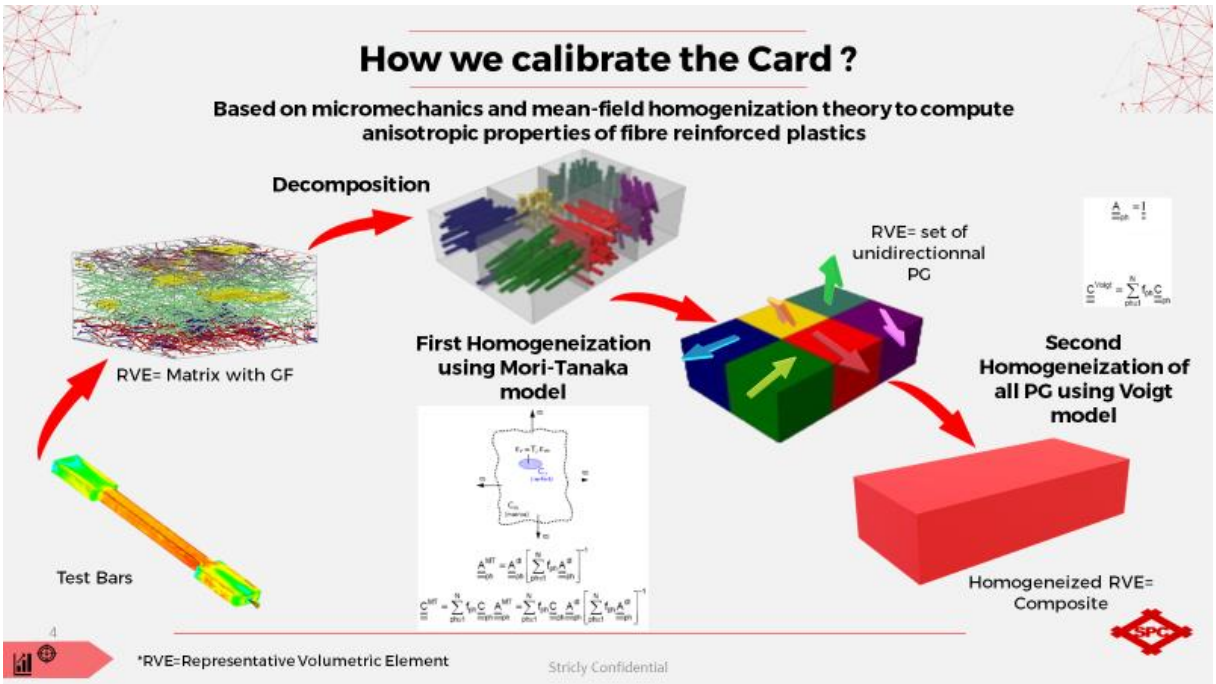


Figure 4-Workflow used for calibration

To calibrate EVP model, we used Norton-Hoff model [5] and Prandtl-Reuss model [6] for isotropic law, we used Von Mises criteria [7].

To establish failure behaviour, Tsai-Hill 3D theory [8] has been applied on each ply (see fig (5)).

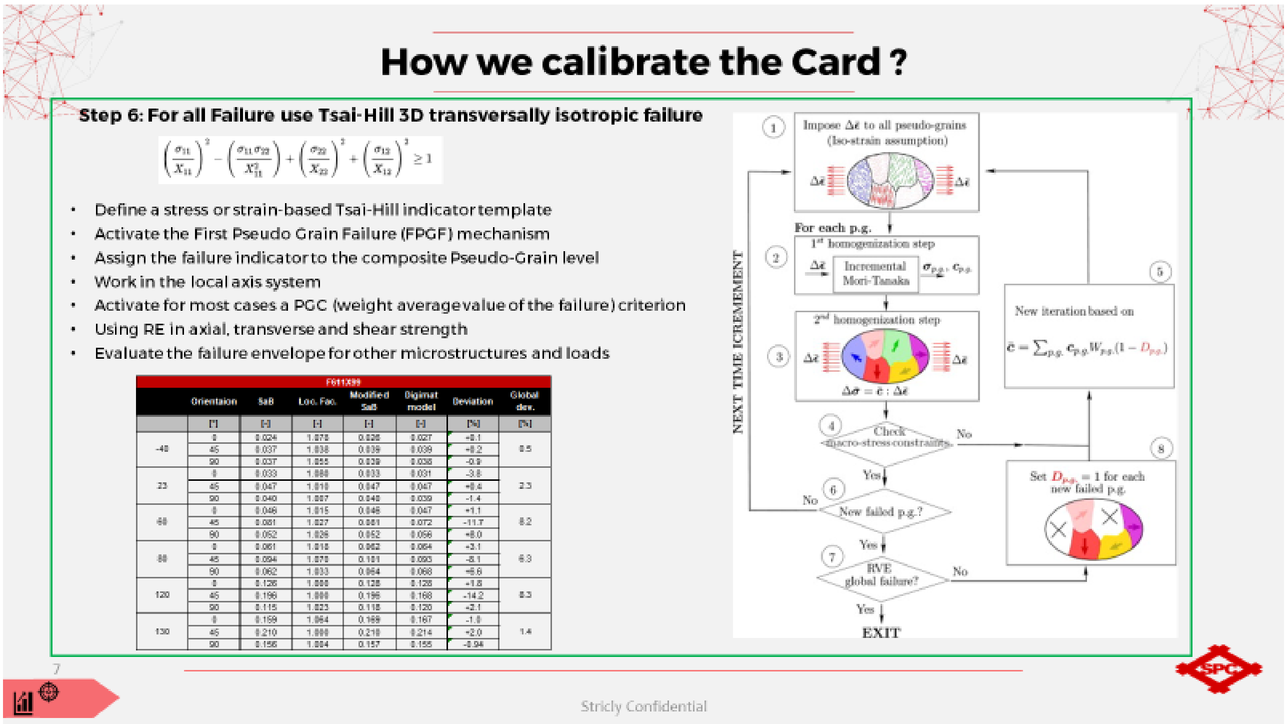


Figure 5-Tsai-Hill failure criteria

Regarding Creep model Tsai-Hill 3D model was apply for failure and reverse engineering was used on axial, transverse and shear strength using a Kelvin-Voigt model [9].

Finally, fatigue calibration used a BASQUIN model [10] and Tsai-Hill 3D criteria for failure (see fig (6)).

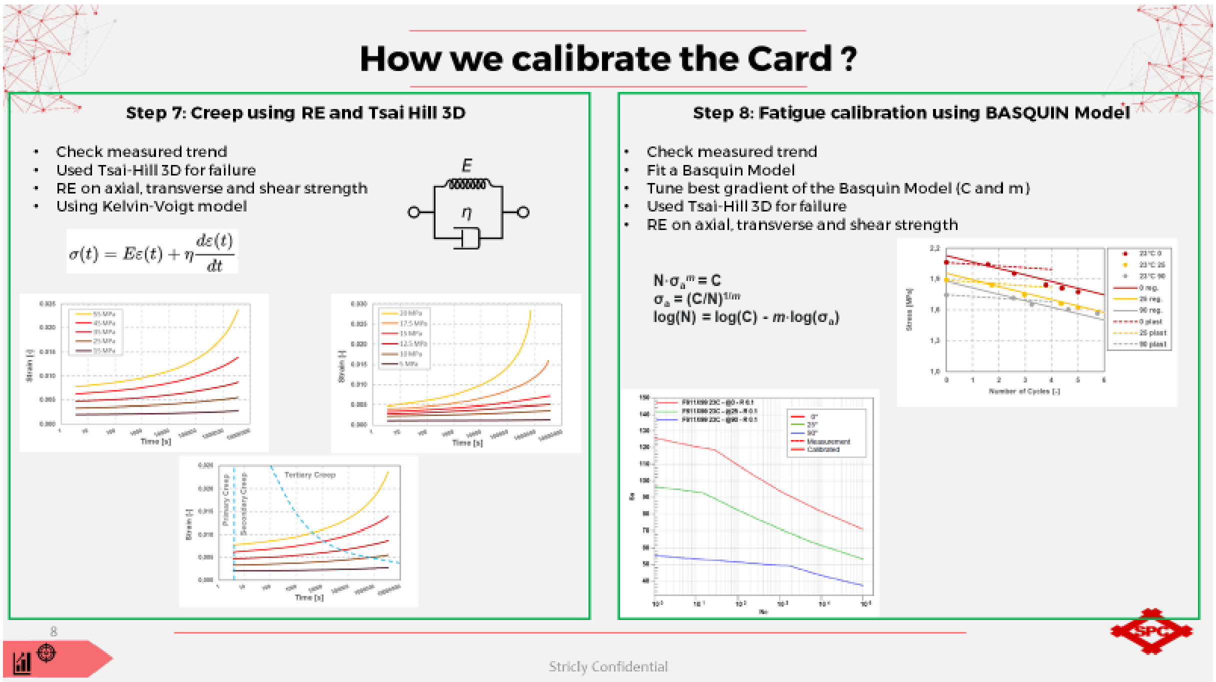


Figure 6-Creep and Fatigue Model

This workflow has been used for a high range of glass fibre content (30% to 50%) and big range of temperature to be apply for various applications (see fig.(7)).

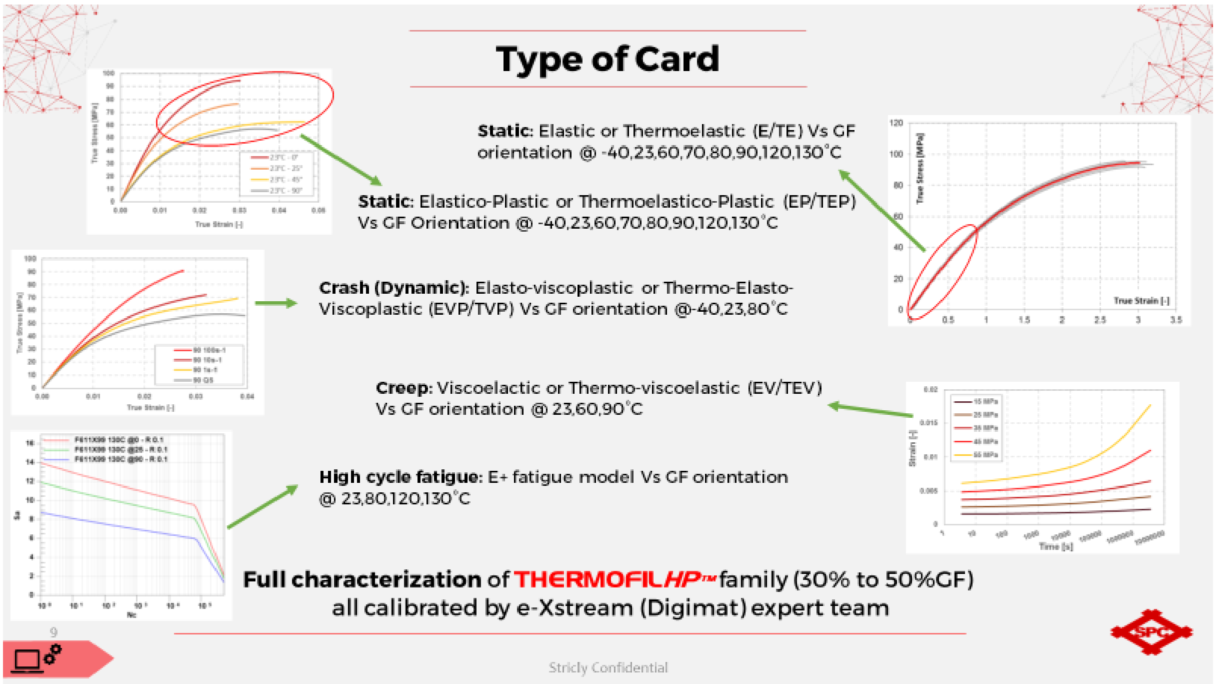


Figure 7-Range of materials cards

3.2 SUMIKA MOLDFLOW

SUMIKA offer to conduct complete and deep Moldflow analysis using MOLDEX 3D software to reduce the time of tuning during the first stage of development.

Thanks to high quality of SUMIKA's Moldflow card, we have performed different MoldFlow analysis and given the best recommendation and process conditions to reduce warpage, welding line and occurrence of porosity into the part. More specifically the two options requested by our customer shows a high level of warpage and a high risk of shrinkage which will occurs a high risk of porosity.

SUMIKA team have proposed other option which show a very level of warpage and smaller shrinkage (see figure (8) and table [2]).

Figure 8-gate location (option 1, option 2, SUMIKA proposal)

	Option 1	Option 2	SUMIKA proposal
Level of warpage	1 mm	1,3 mm	0,5 mm
Risk of porosity	High	High	low

Table 2- Warpage and risk of porosity

As SUMIKA proposal shows the less warpage prediction and a low risk of porosity, this option has been used for injecting the pedal box.

3.3 SUMIKA FEA

FEA has been conduct using MARC solver and the non-linear anisotropic approach taking in account the Glass fibres to achieve better prediction (see figure (9)).

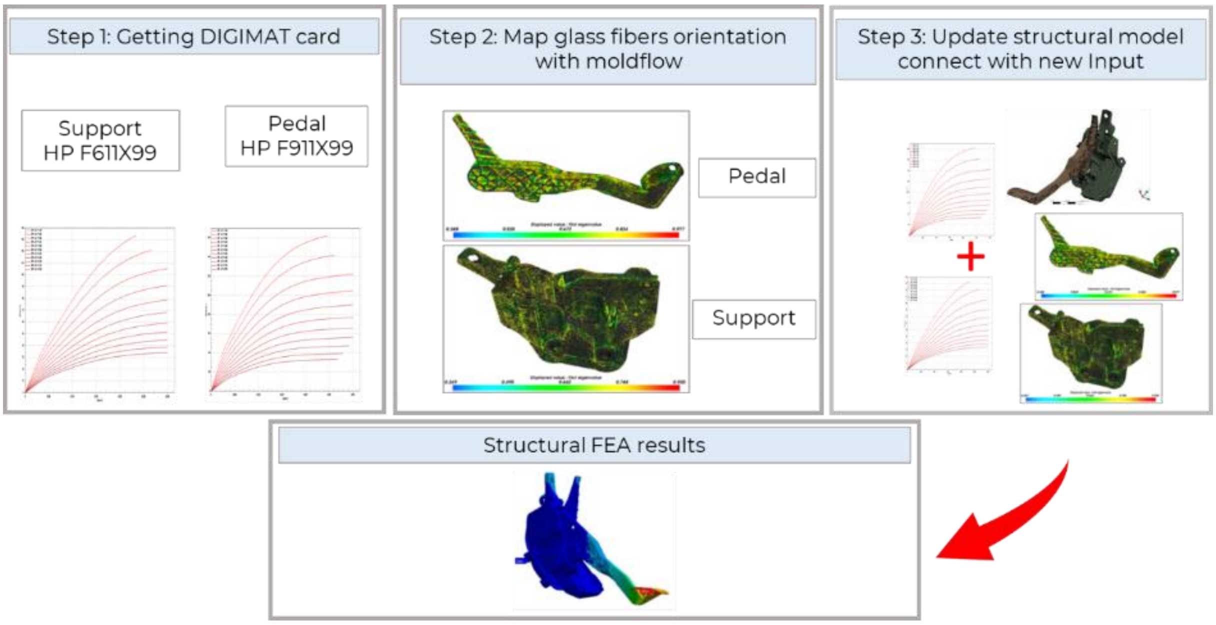


Figure 9- Process used to make FEA analysis

The process used to make FEA analysis is quite top of edge as it takes in account the glass fibre orientation coming from injection simulation (manufacturing data). The process works in 4 steps, the first step is to get the DIGIMAT card of material (behaviour of material at different glass fibre orientation). The SUMIKA card has been built by cutting some test bars from injected plate, then we cut some ISO bars (ISO 8256 type 3) at different glass fibre orientation (0°, 90° and 45°). Furthermore, we also check the fibre length and the fibre orientation depending the thickness by tomography (µCT scan). This allows to get a very high quality of material card to get the best prediction.

The second step is to get the glass fibre orientation coming from the Moldflow analysis (mapping).

The third step is to load into DIGIMAT RP (multiscale non-linear anisotropic software) the card and the mapping coming from the injection process.

The fourth step is to load the combination (coupled analysis) into MSC MARC solver and then get the FEA analysis as standard way but taking in account the process of manufacturing the parts.

For the FEA analysis, different loading case has been applied on the pedal box and brake pedal has shown in table [3] below.

	Load case	Direction	Force (DaN)	Angle	Cycles	Condition
1	LONGITUDINAL STIFFNESS	Fxz	+50	0°	1	23°C
2	SIDE STIFFNESS	Fy	+10	0°	1	23°C
3	SIDE STIFFNESS	Fy	+100	0°	1	23°C
4	PLASTICITY/FAILURE	Fxz	+100	0°	1	23°C
5	PLASTICITY/FAILURE	Fxz	+100	0°	1	65°C & 85% HR
6	PLASTICITY/FAILURE	Fxz	+150	0°	1	23°C
7	PLASTICITY/FAILURE	Fxz	+250	0°	1	23°C
8	PLASTICITY/FAILURE	Fxz	+250	0°	1	65°C & 85% HR
9	PLASTICITY	Fxz	+150	15°	1	23°C
10	PLASTICITY	Fxz	+150	15°	1	65°C & 85% HR
11	PLASTICITY	Fxz	+100	0°	1	23°C
12	PLASTICITY	Fxz	+100	0°	1	65°C & 85% HR
13	PLASTICITY	Fxz	-40	0°	1	23°C
14	PLASTICITY - LCF	Fxz	+150	0°	10	23°C
15	PLASTICITY - LCF	Fxz	+150	0°	10	65°C & 85% HR
16	PLASTICITY - LCF	Fxz	+200	0°	10	23°C
17	PLASTICITY - LCF	Fxz	+200	0°	10	65°C & 85% HR
18	PLASTICITY - LCF	Fy	+60	-45°	10	23°C
19	PLASTICITY - LCF	Fy	+60	-45°	10	65°C & 85% HR
20	PLASTICITY/FAILURE	Fxz	+150	0°	1	23°C

Table 3-Loading case

FEA analysis has been conduct and some results has been shows below (see figure (10)).

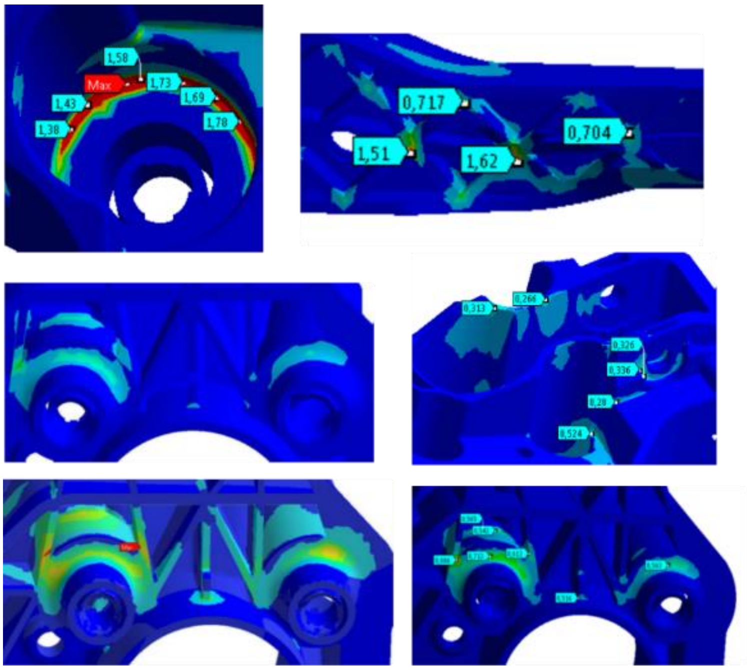


Figure 10- Differents FEA results

All FEA results shows no risk of failure. In some loading cases, a residual displacement is observed which is at the limit of the product, but without any failure. This is should be check carefully.

3.3 FEA results Vs test on parts

Thanks to all results describe above, one mould has been produced and test according the different loading case has been conducts.

Some comparison of FEA results versus results on test part are show in the table [4].

Loading cases	FEA prediction (mm)	Part results
Load/Unload during 5s at 250 DaN/ 65°C	25,8 (maximum displacement) 4,2 (residual displacement)	23,5 (maximum displacement) 3,9 (residual displacement)
10 cycles Load/Unload at 200 DaN/ 65°C	18,8 (maximum displacement) 4,41 (residual displacement)	19,2 (maximum displacement) 4,6 (residual displacement)

Table 4-Results coming from some FEA analysis

The comparison table above shows a very accurate prediction compare to real behaviour measured on part. This is due to high quality card of material (Glass fibre orientation, fibre length and orientation into the thickness) combining with non-linear anisotropic approach with taking in account the process (Glass fibre orientation into the parts). This approach allows to simulate cycles load and maintaining load during some seconds with a relatively good prediction. This is allowing to our customer to produce the below parts (see figures (11) and (12)).

Figure 11-Pedal box in THERMOFIL HP® F611X99

Figure 12- Brake pedal in THERMOFIL HP® F911X99

4 Conclusions

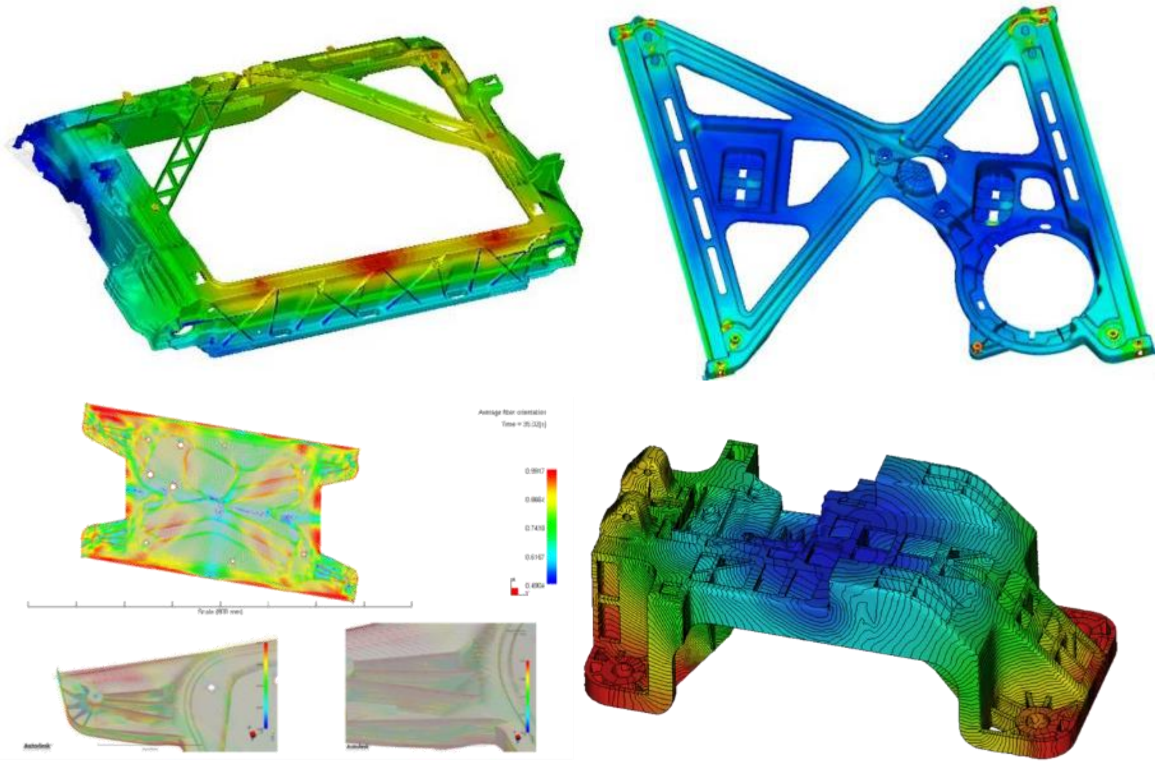
THERMOFIL HP® series out-perform traditional engineering plastics as PA6-GF, PA66-GF and PBT-GF also at elevated temperature which is introduce a new engineering PP glass fibre reinforced into automotive industry. This allows to achieve $C0_2$ emissions requirement for high demand parts throw lightweight solutions (see table [5]).

	THERMOFIL HP® F611X99	**THERMOFIL HP® F911X99**
PA6-GF30	17% weight saving	-
PA6-GF50	-	15% weight saving

Table 5-Weight saving

THERMOFIL HP® can deliver substantial weight and cost saving due to raw material volume costs and process costs (around 15 to 40%). THERMOFIL HP® series combine with non-linear anisotropic approach allows to minimise time of development to develop faster with a very good accuracy, this is pushing the boundaries of short glass fibre PP, unlocking new opportunities and applications. This offers no limit for structural, door, cockpit or under hood applications.

Considering the very good properties observe with THERMOFIL HP®, it has been possible to replace traditional engineering plastics in various applications.



5 References

[1] INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION: "CO_2 emission standards for passenger cars and light-commercial vehicles in the European union", page 9, ICCT, updated in May 2020.

[2] 7th European LS-DYNA Conference: "Multi-scale modelling of crash & failure of Reinforced plastic parts with DIGIMAT to LS-DYNA interface", L.Adam; A.Depouhon; R.Assaker, 2009

[3] Mori, T., Tanaka, K., 1973. Average stress in matrix and average elastic energy of materials with misfitting inclusions. Acta Metallurgica 21 (5), p.571–574

[4] Voigt, W. (1889). Ueber die beziehung zwischen den beiden elasticitätsconstanten isotroper körper. Annalen der Physik, 274(12):p.573–587.

[5] F. H. NORTON, The creep of steel at high temperature, McGraw Hill, New-York, 1929 ; H. J. HOFF, Approximate analysis of structures in presence of moderately large creep deformations, Quart. Appl. Math., 12 (1) (1954), p. 49.

[6] A. REUSS, Zeitschrift für Angewandte Mathematik and Physik, 10 (1939), p. 266.
Johanna Vogel-Prandtl, « Ludwig Prandtl. Ein Lebensbild. Erinnerungen, Dokumente », Nachdr. der Ausg. Göttingen, Max-Planck-Inst. für Strömungsforschung, 1993 ; Univ.-Verl. Göttingen, 2005

[7] Von Mises, R. (1913). "Mechanik der festen Körper im plastisch-deformablen Zustand". Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-Physikalische Klasse.

[8] Hill, R., 1965. A self-consistent mechanics of composite materials. Journal of the Mechanics and Physics of Solids 13, P.231.

[9] Woldemar Voigt, « Über die innere Reibung der festen Körper, insbesondere der Krystalle – Erster Teil », Abhandlungen der Königlichen Gesellschaft von Wissenschaften zu Göttingen, vol. 36, 1890, p. 3-47

[10] O. H. Basquin, "The Exponential Law of Endurance Tests," American Society for Testing and Materials Proceedings, Vol. 10, 1910, p. 625-630.