EURONANOFORUM
Modelling activities as a tool to optimize materials, products, process and performance

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Case studies from IK4-TEKNIKER in Modelling :

Materials and Product Optimization:

- Atomistic modelling and molecular dynamics **nanocomposites and nanopigments**, *Borja Coto (borja.coto@tekniker.es ; Doctoral Thesis)*
- Optimization of a **nebullizer** design, *Jon Lambarri (jon.Lambarri@tekniker.es)*

Process Optimization:

- Numerical modelling in **Laser** processing, *Jon Lambarri*
- **Cutting** operations, *Itxaso Cascón (Itxaso.gascon@tekniker.es)*
- **Curing** treatment, *Cristina Monteserin (cristina.monteserin@tekniker.es, Doctoral Thesis)*

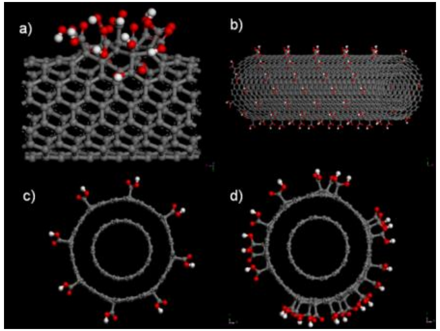
Performance Optimization:

- Modelling **elastomers and Bearings** (Aitor Fernandez, aitor.fernandez@tekniker.es)
- **Moulds durability** in function of the type of failure modes, *Borja Zabala (Borja.zabala@tekniker.es; Doctoral Thesis)*

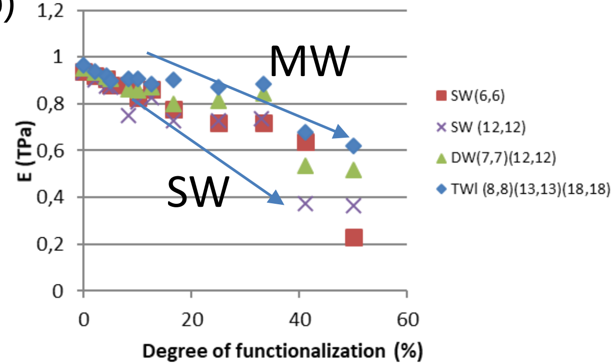
Materials Optimization: Polymer Composites Functionalization

Objective: innovative polymer composites filled with CNT to obtain **nanostructured materials**

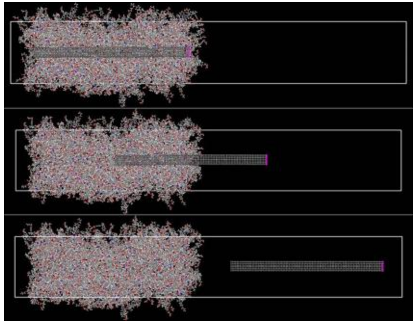
Modelling goal: Study the influence of **functionalization on mechanical properties** of CNTs. **Modelling tool: MD** (Acceleris, Materials Studio)

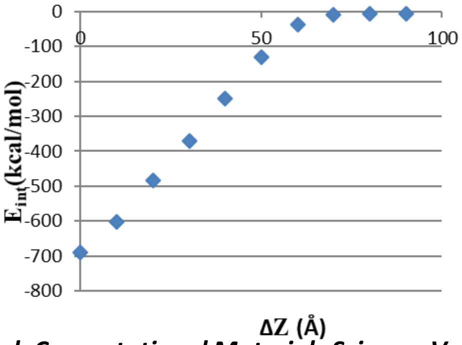


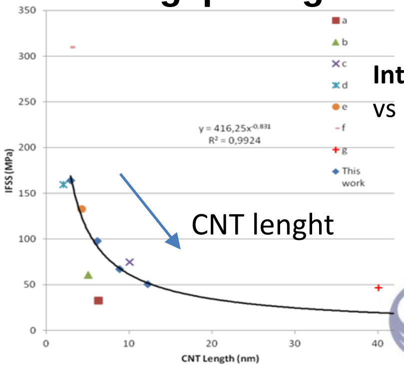
- Young's modulus **decreases** as **% of functionalization increases**.
- **The decrease** is **less critical in MWCNT** than in SWCNTs



MD modelling: Interphase Interaction between CNT & polymeric matrix **simulating pulling out** of the CNT.







Interfacial Shear Strength vs Length of CNT.

POCO

EU project

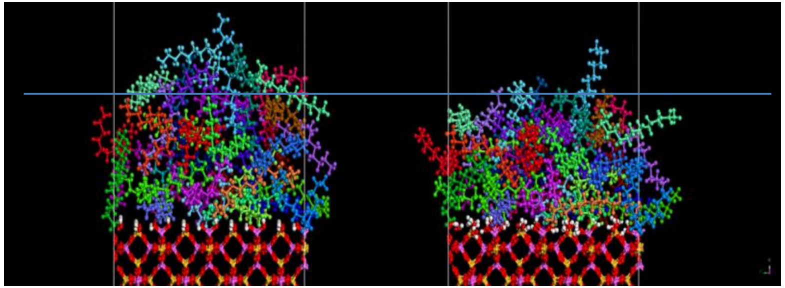
B. Coto et al. Computational Materials Science. Vol 50, 12, 2011, pp 3417–3424

Materials Optimization: Absorption PCMs/Pigments

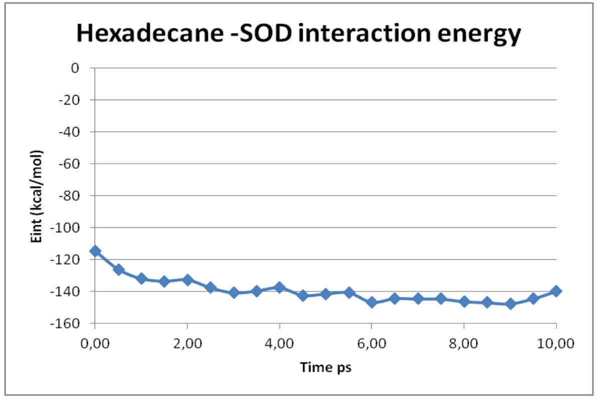
NANO PIGMY **EU project**

Project Objective: develop multi-functional and cost-efficient **ceramic nanopigments** for paint, plastic and concrete

- **Modelling Tools: Atomistic Monte Carlo simulations to study** absorption of molecules (PCM) in porous medium



Configurations of hexadecane molecules adsorbed on a surface before and after 10 ps of MD run



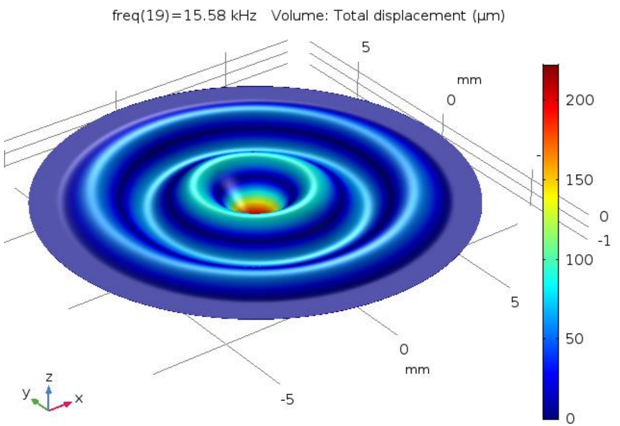
Evolution of the interaction energy between hexadecane molecules layer and the SOD surface

- Evolution (10ps) of **adsorbed molecules** to determine their suitability to be adsorbed in a nano porous surface
- The MD simulation **show the stability** in time of the absorbed layer

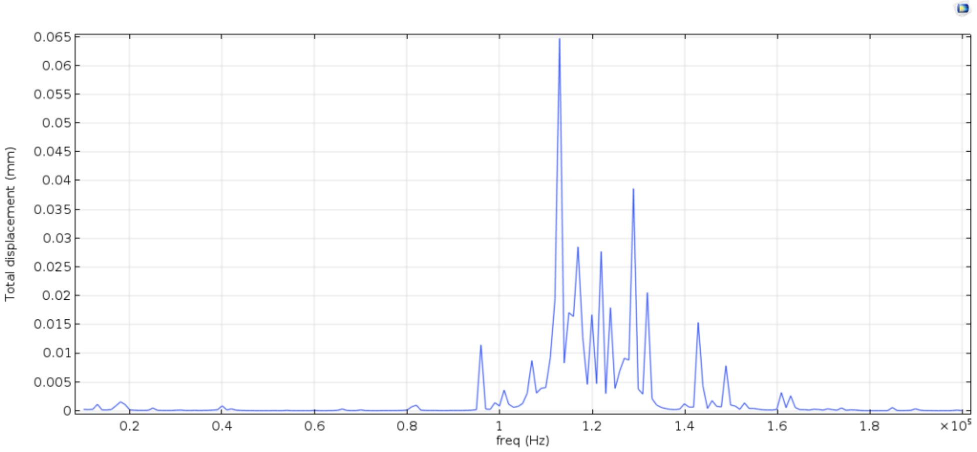
The Nanopigmy project has received funding from the European Community's Seventh Framework Programme (FP7-NMP-2011-SME-5) under grant agreement no 280393.

Product Optimization: Optimization of a nebulizer design

- **Objective**: Optimize a nebulizer design and find appropiate operation parameters
- **Modelling Tools:** Multiphysics COMSOL



Piezoelectric simulation of the membrane

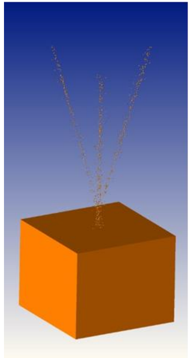


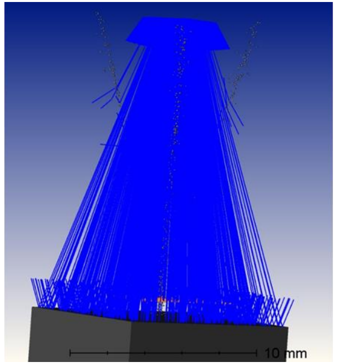
Output : Optimized geometry and frequency spectrum

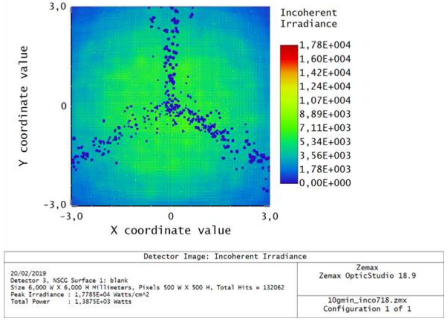
The research leading to these results was carried out in cooperation with **LAINO MEDICAL**

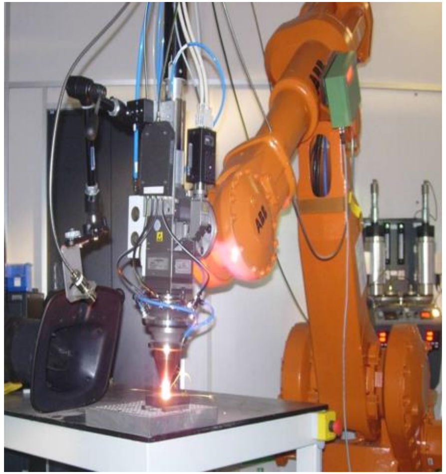
Process Optimization: Ray tracing during Laser Melting Deposition

- ***Goal***: Study **laser-matter interactions** for laser additive manufacturing of metals to **predict the thermal and mechanical response** of the parts
- ***Modelling Tools:*** *ZEMAX, OpenFOAM, SYSWELD*





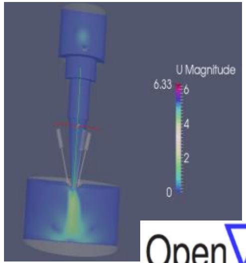




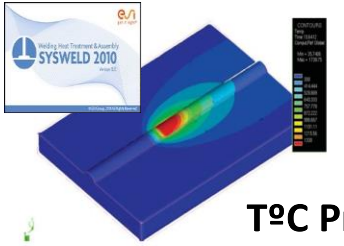
Import **powder cloud**

Ray tracing from a laser source to the substrate

Output : **Effective power density** distribution for thermo-mechanical FEM simulation

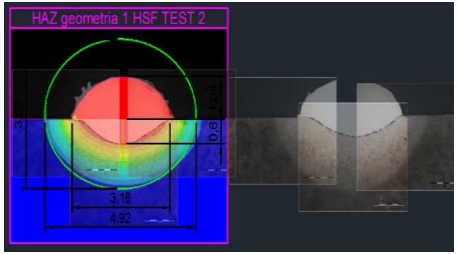


OpenFOAM



(a) External surfaces isotherms

TºC Processing



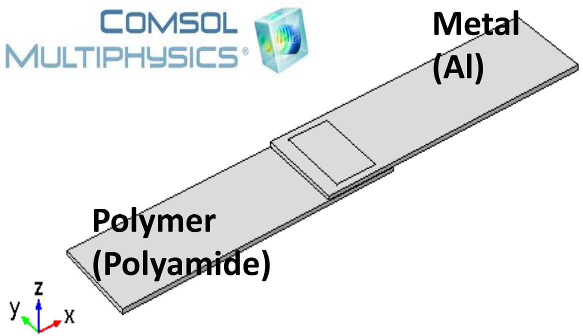
SYSWELD 2010

Deposited track geometry

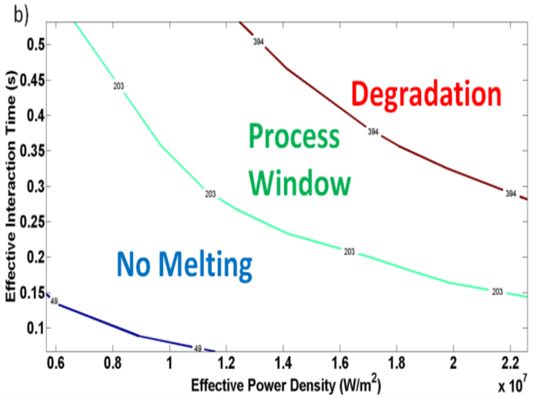
Process Optimization: Laser joining hybrid polymer-metal

Goals: Obtain the process **parameter window** avoiding lack of melting or polymer degradation
Modelling tools: COMSOL Multiphysics

Applications: Hybrid components for lightweight structures



Test part configuration



Numerical parameter map

Funds from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement 309993. **Partners:** Fraunhofer ILT, Faurecia, Valeo, PSA, Armines, Andaltec, Lasea

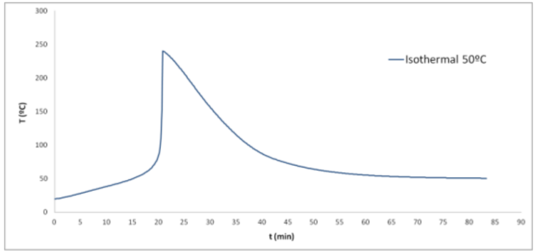
Process Optimization: Curing epoxy resins

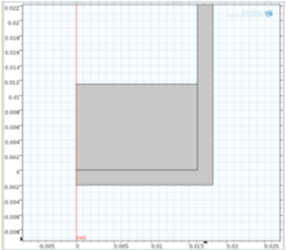
EMACOMP project

Objective: to study the **curing kinetic** of an **epoxy resin** and the relationship between **the curing process parameters** and final **properties** of the thermoset networks

Modelling Tools: FEM Simulations, COMSOL, **Goal**: Coupling between **heat transfer & chemical kinetics**

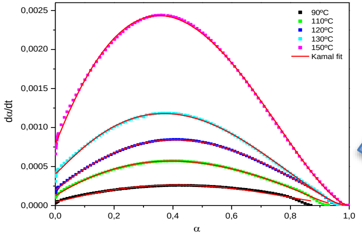
Objective	Impact
Curing evolution in a viscoelastic thermoset polymer resin	Increase **process control**
Predict and optimize curing cycles	increase **process efficiency**
Obtain **high degrees** of **curing**	Improve **quality**
Avoid heat degradation	increase **durability**
Reduce curing times	Reduce **cost**





Process Optimization: Curing epoxy resins

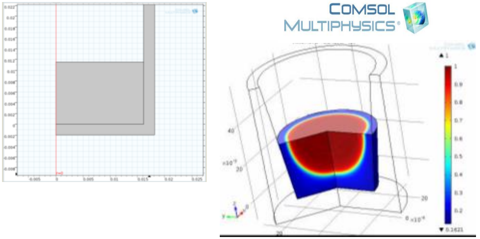
1. **Thermal characterization** of the curing kinetics



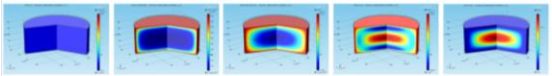
2. Obtaining of a **kinetic model** corresponding to the curing behaviour of a specific system (resin-curing agent)

$$d\alpha/dt = (k_1 + k_2\alpha^m)(1-\alpha)^n$$

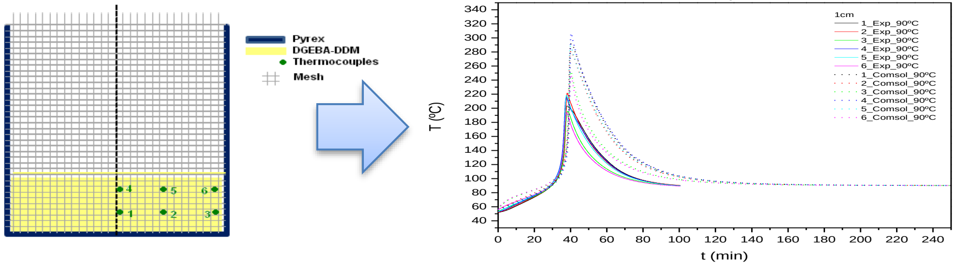
3. **Simulation of a real piece**, coupling chemical kinetics and heat transfer, using Levenberg-Marquardt **non-linear regression analysis**



Mapping **TºC and curing degree** at any point and any time



Good correlation in TºC values. Simulation **vs** Experimental

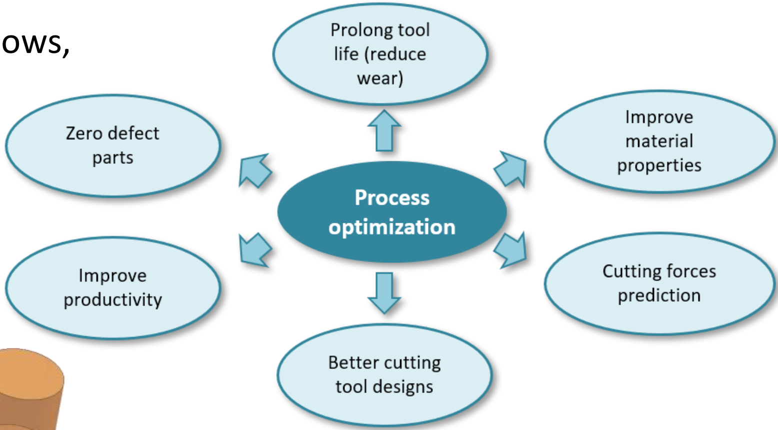


4. **Validation of simulation** (experimental test)

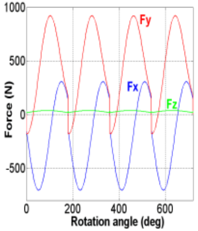
C. Monteserín, M. Blanco, J.M. Laza, E. Aranzabe, J.L. Vilas. "Thickness effect on the generation of temperature and curing degree gradients in epoxy–amine thermoset systems" Journal of Thermal Analysis and Calorimetry (2018) 132:1867–1881

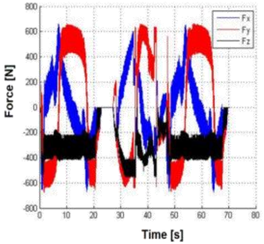
Process Optimization: Cutting and Machining

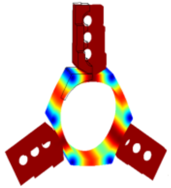
Objective/Impact: optimization of **manufacturing** processes. Models allows, **reducing the number of experiments** and **reducing costs.**

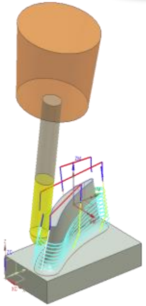


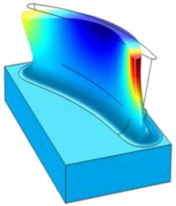
- Cutting and machining (**Prediction of cutting force**
  - stability (chatter and vibrations)
  - Material removal
  - **Surface finishing forecast**
  - CAD/CAM Integration
  - Chip formation (**mechanical & thermal effects)**
  - **Clamping distortion**
- Heat Treatments
- Modal analysis
- Tool design
  - Tool geometry and performance analysis
  - Design of a chip breaker
  - Better milling tooth paths

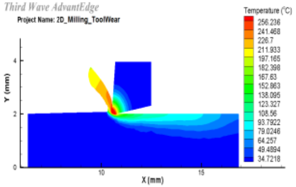




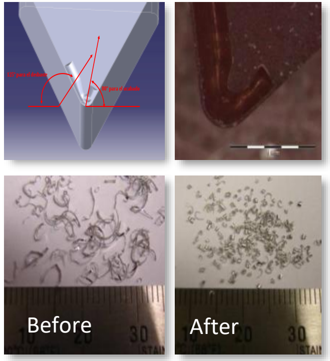








Design of a chip breaker

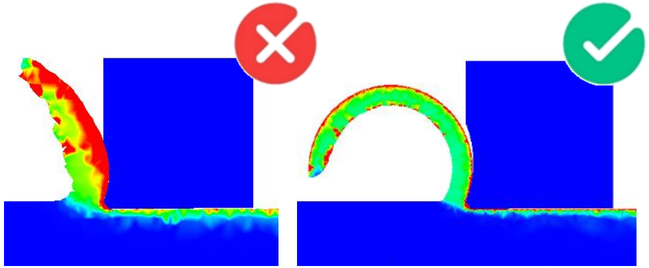


IK4 TEKNIKER Research Alliance

Process Optimization: Modelling tool design

Objective: Design of chip-breakers geometry by FEM simulation

Modelling Tool: Advantage



Cutting force = 197.4 N
Temp = 198,7 ºC

Cutting force = 124.5 N
Temp = 170.6 ºC

+ Laser Additive manufacturing of the chip-breaker

1 Without CB

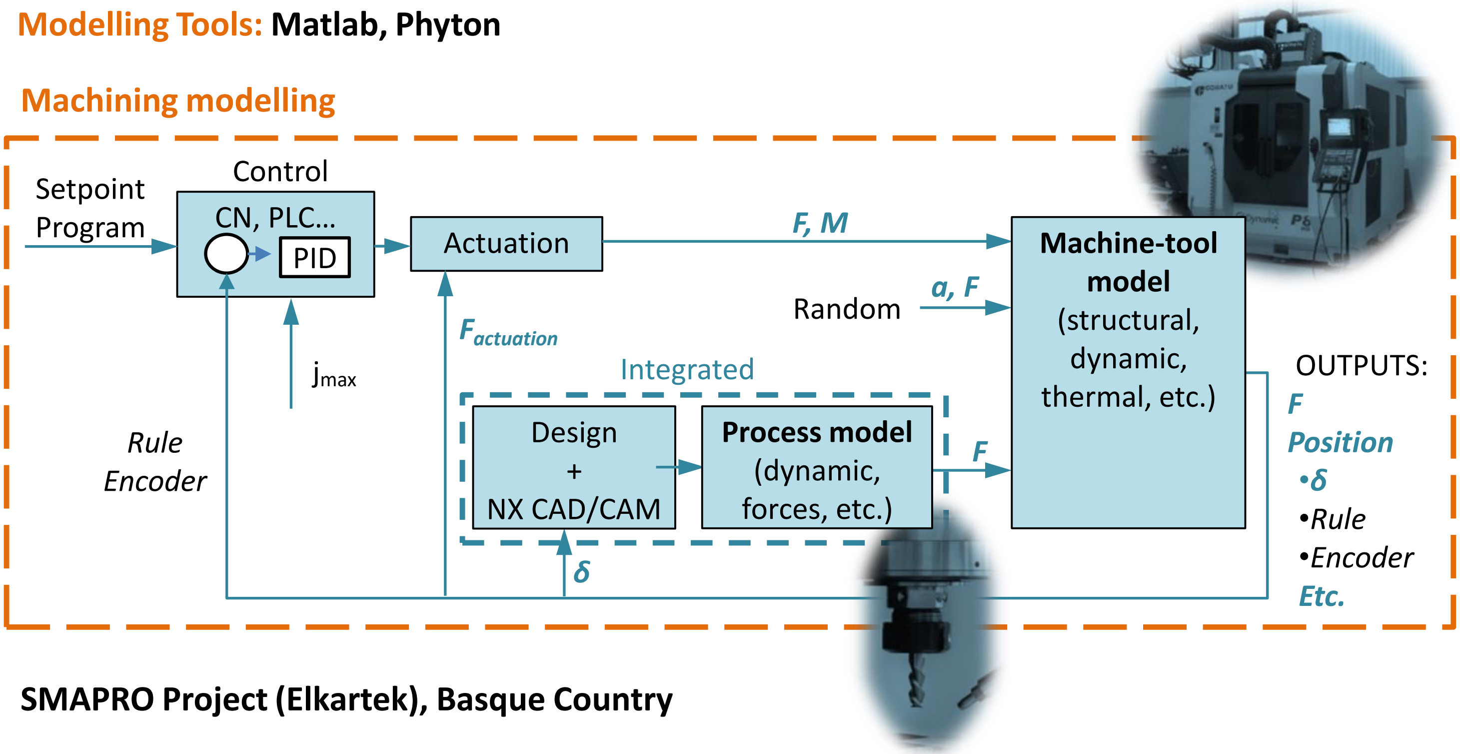
2 With CB

Turning of ductile materials (i.e. aluminium)

Process Optimization: Model integration & control

Modelling Tools: Matlab, Phyton

Machining modelling

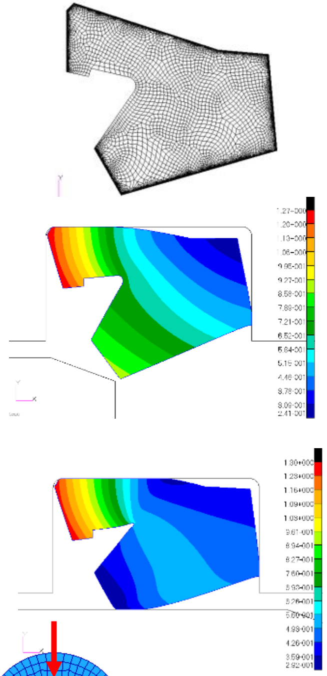


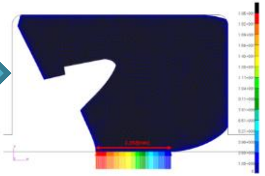
SMAPRO Project (Elkartek), Basque Country

Performance Optimization: Modelling elastomeric sealing systems

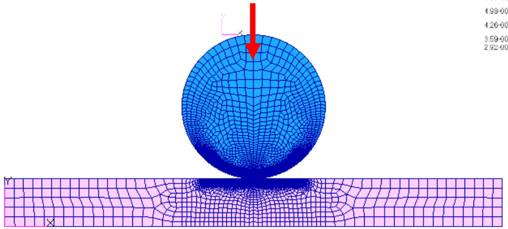
- Necessary data for building a model:
  - Basic properties
  - Mechanical tests
  - Material behaviour models

Objective: Simulation of the actual sealing system, to acquire information to design simplified tribological tests





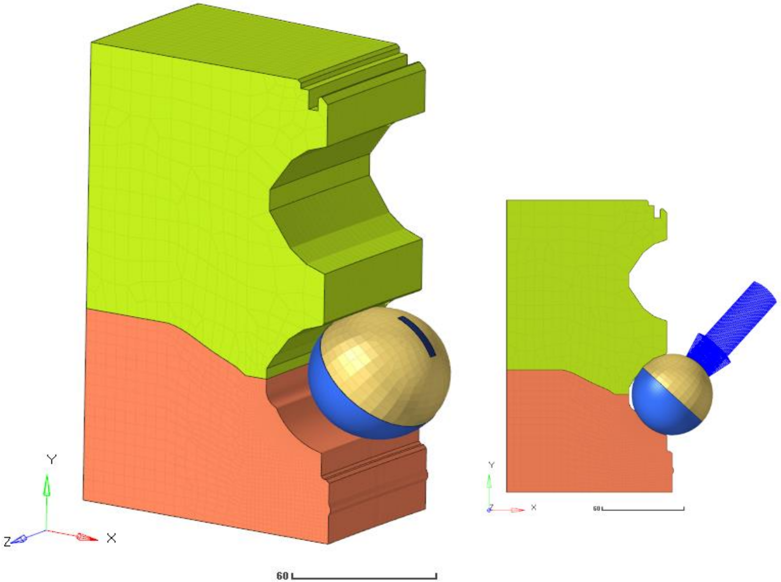
FEM of the component
at actual working conditions

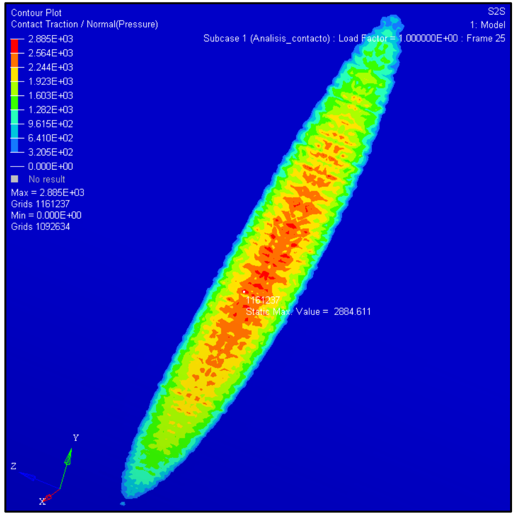


Definition of load for tribological testing conditions

Performance Optimization: Modelling Ball Bearings

- Modelling tools (FEMS, KISSsoft, BEARINX)
- Calculation of the **contact pressure**, useful for the **prediction of different failures:** Rolling contact fatigue, false brinelling… (analytical formulas)





Performance Optimization: Moulds (plastic and metal injection)

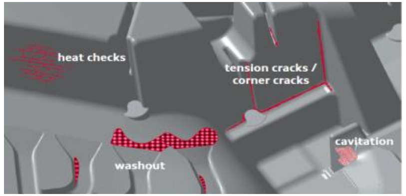
MODELING MOLD WEAR PERFORMANCE

THE FAILURE MECHANISM

- Thermal Fatigue
- Die Soldering
- Erosion
- Abrasion
- Corrosion

High Pressure Die Casting

Plastic Injection Molding

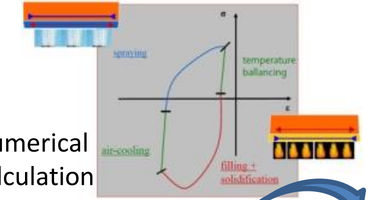


THE NEED

Example of Durability needs:
100-300.000 castings
Real durability:
5000-25000 cycles
Substitution cost of mold insert: 50000€
Shutdown cost/day: 3000€

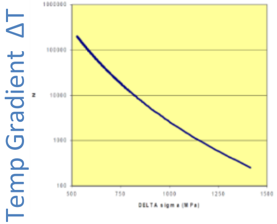
Financed by EU Commission Project Music: FoF-ICT-2011.7.1
Smart Factories: Energy-aware, agile manufacturing and customization

Performance Optimization: Modelling thermal fatigue



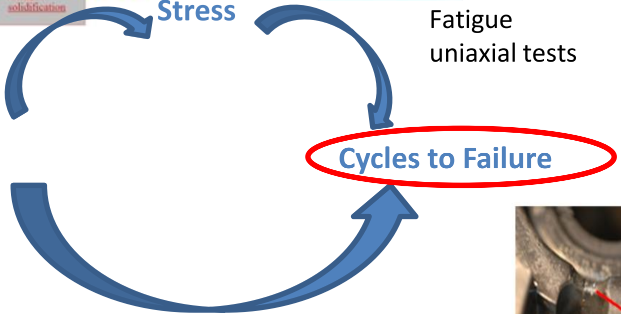
Numerical calculation

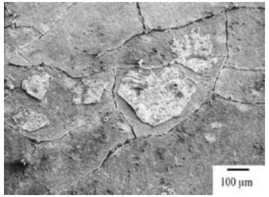
Fatigue uniaxial tests



Cycles N

N (cycles) = f (Δσ)





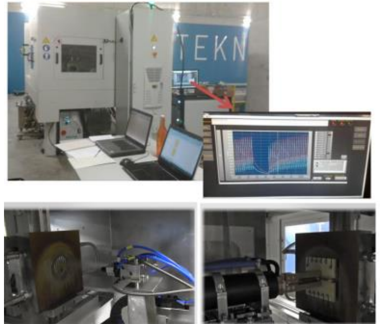
Influence:

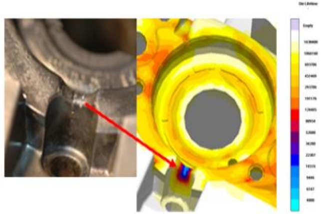
-Material properties

-Thermal stresses

- Stress concentrators

Thermal Fatigue Test bench





Temperature

N (cycles) = f (T^{o}C)

Crack Initiation Prediction

Software Validation

HPDC Example:

4. Wear Modelling Implementation

Thermal Fatigue
N (cycles) = f (stress)
Where
S: thermal stress calculated (820-920 MPa)

Die Soldering
N(cycles)= f (Temperature, pressure)
Where:
T: *Mould surface temperature* (350 - 450ºC)
P: *Pressure in the mould surface* (0 - 7 MPa),
K: *depending on lubricant*

Erosion
Wear(µm/h)=f (angle, speed, hardness)
Where:
VEL: flux speed (32-64m/s)
ANG: impact angle (15-90º)
H: Hardness (200-900HV)

Reference case:

INPUT		
MaxT	400	°C
Thermal stress level	870	MPa
Pressure	1	MPa
Impact speed	50	m/s
Impact angle	30	°
Lubricant	2.68	D
Die material	1	H13

Failure prediction:

OUTPUT		
Thermal Fatigue	7369	Cycles
Die Soldering	956	Cycles
Erosion	17269	Cycles

Improved case:

INPUT		
MaxT	400	°C
Thermal stress level	820	MPa
Pressure	1	MPa
Impact speed	40	m/s
Impact angle	30	°
Lubricant	1	A
Die material	1	H13

Failure prediction:

OUTPUT		
Thermal Fatigue	**18026**	**Cycles**
Die Soldering	**11286**	**Cycles**
Erosion	**30698**	**Cycles**

time for mould reparation x 2
time for maintenance stops x 10

CONCLUSIONS

The use of modelling to:

- Molecular Dynamic and Atomistic modelling to predict **properties at the nanoscale**
- **Piezoelectric simulation** has been used for product (nebulizer) design
- Optimization of **laser and curing processing** by modelling
- **Machining models** to improve the process, reduce the experimental set-up
- **New tool geometries** to reduce manufacturing errors.
- Use **FEM tools** to **predict failure** modes analytically and define tribological tests
- Prediction failure modes lifetime: constructing innovative equipment's, reproducing wear mechanisms, **building lifetime equations from experimental data**

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Research Alliance