NEW HOMOGENEOUS GELLED OILS FOR SPACE MECHANISMS LUBRICATION

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BACKGROUND AND PURPOSE

Goal of the project:

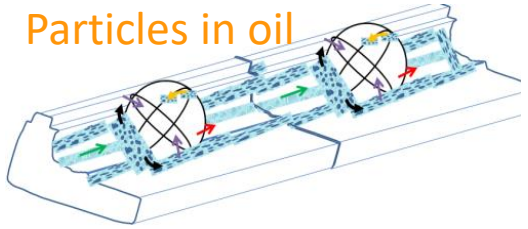
Develop new **homogeneous** gels able to replace PTFE MoS_2-based greases (such as Braycote, Lubcon, Maplub,…)

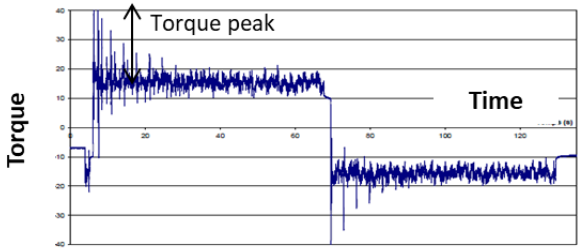
How to solve these issues ?

- **Homogeneous gels** : no phase separation over time
- **Rheofluidifying properties** : low viscosity of the gels during the rotation of the ball bearings , high viscosity at rest

Drawback of current technology :

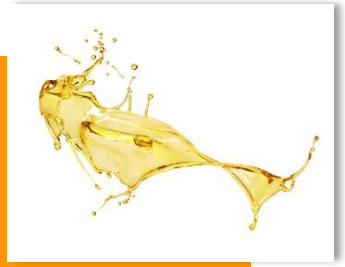
Particles in oil





- **failure** of the mechanism due to surface creeping of liquid oil
- **lack of lubricant** in contact over time
- **high torque peaks** when used in ball bearings at low rotation speeds

SPECIFICATIONS

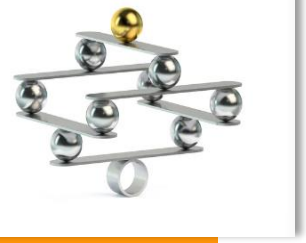


Base oils

- **NYE2001A**
  CycloPentane oil (Hydrocarbon)
- **FOMBLIN Z25**
  PerFluoroPolyEther oil (PFPE)

Vacuum compatibility: (ECSS-Q-70-02A standard)

- Vapor pressure < 10^{-8} Torr (20°C)
- TML < 1%
- CVCM < 0.1%
- RML < 1%
- Evaporation rate under 10^{-5} Torr < 10^{-5} mg.cm^2.s^{-1} (100°C)



stability

- Constant use :
  -120°C <T< +120°C
  Occasional use : < +200°C
- Compatibility with metals, PTFE, Phenolic resins, …
- Shelf life and in use lifetime : > 10 years
- No space radiations susceptibilty

Viscosities (Similar to Maplub SH and PF)

- **In NYE2001A :**
  30±10 Pa.s (10s^{-1}) and 7±2 Pa.s (100s^{-1})
- **In Fomblin Z25 :**
  44±10 Pa.s (10s^{-1})
  8±2 Pa.s (100s^{-1})

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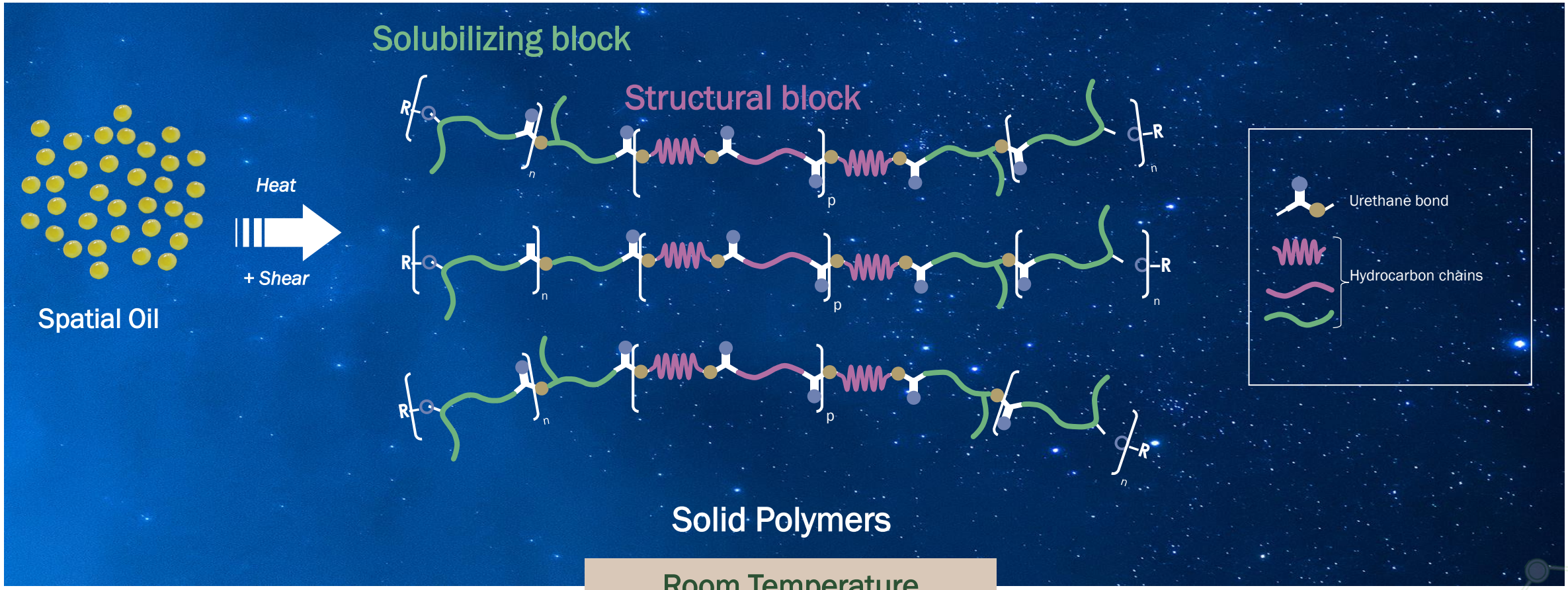
R&D Strategy: self-assembly of supramolecular polymers



Gelation mechanism

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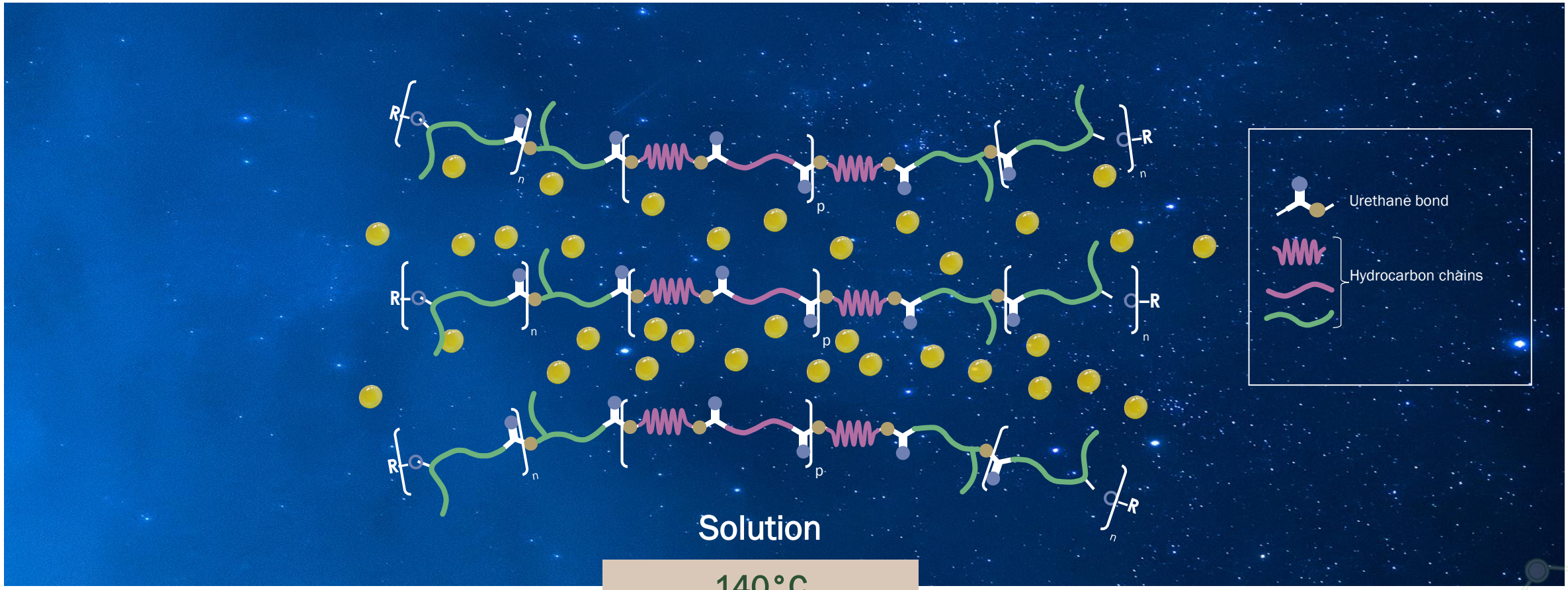
R&D Strategy: self-assembly of supramolecular polymers



Gelation mechanism

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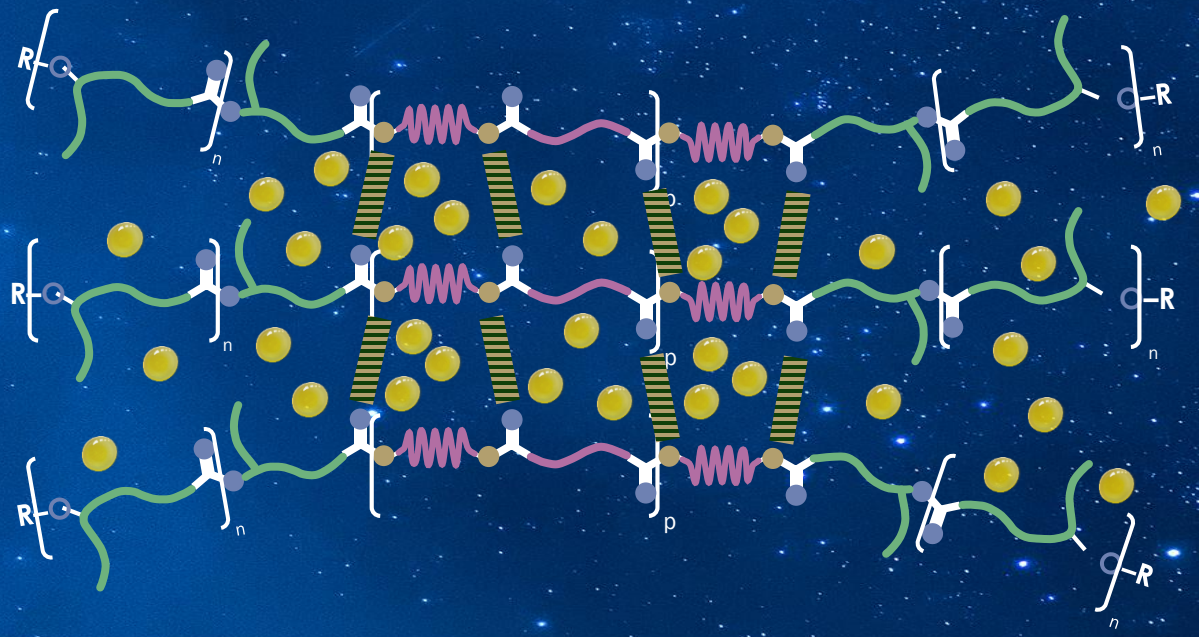
R&D Strategy: self-assembly of supramolecular polymers

Solubilizing block:
Oil soluble

Structural block:
Self-assembly

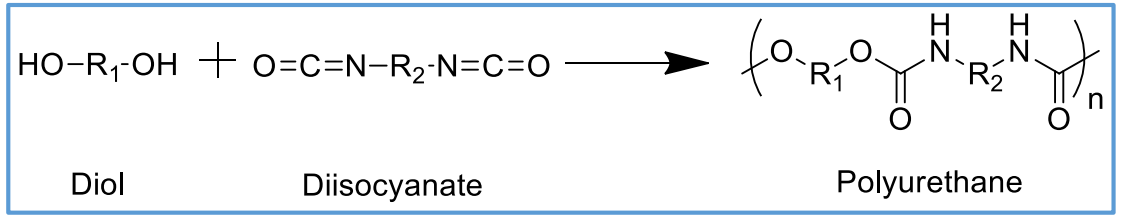


Room temperature

Physical / Reversible Network
- Highly Shear-sensitive gels

SYNTHESIS OF NEW GELATORS

Synthesis of POLYURETHANE (PU)



01

- Good availability of starting materials

02

- large variety of oil soluble diols and diisocyanates

03

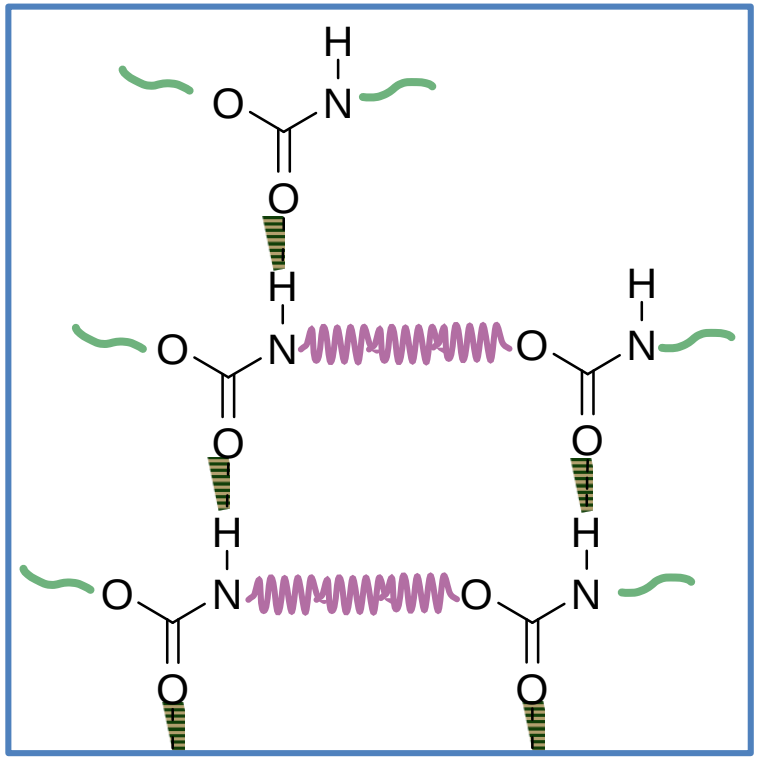
- Good thermal stability

04

- High molecular weight = very low vapor pressure and mass loss

05

- Selection of Solubilizing Block depending on the oil to viscosify



Viscosification of NYE2001A

2 steps synthesis:

Solubilizing block

- functionalization of the polyolefine by a diisocyanate

Structural block

- chain extension using a small molecular weight diol
- termination reaction by an alcohol

2 Polyurethanes:

PU2000 medium molecular weight

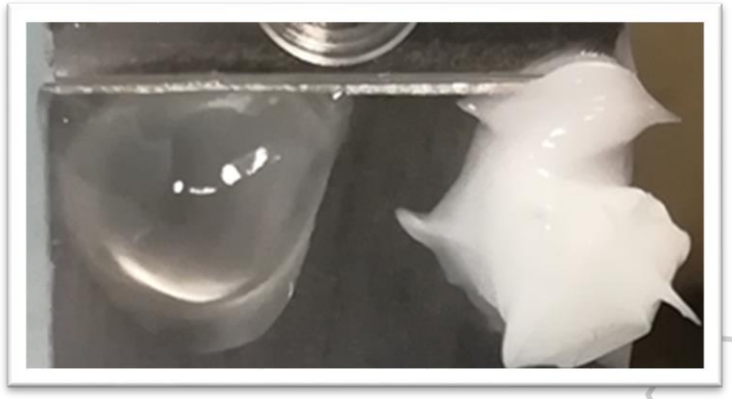
PU3000 high molecular weight

Hot solubilization in NYE2001 (IT-DEX20003/IT-DEX20004):

- Concentration : 10 to 15%
- Temperature : 140°C
- Vacuum: 10^{-2} bar
- Solubilization time : 1 to 2 hours

Translucide homogeneous gel

NYE2001A-based gel *MAPLUB SH-100B*



First characterizations of NYE2001A/PU GELS

Medium Mn
PU2000

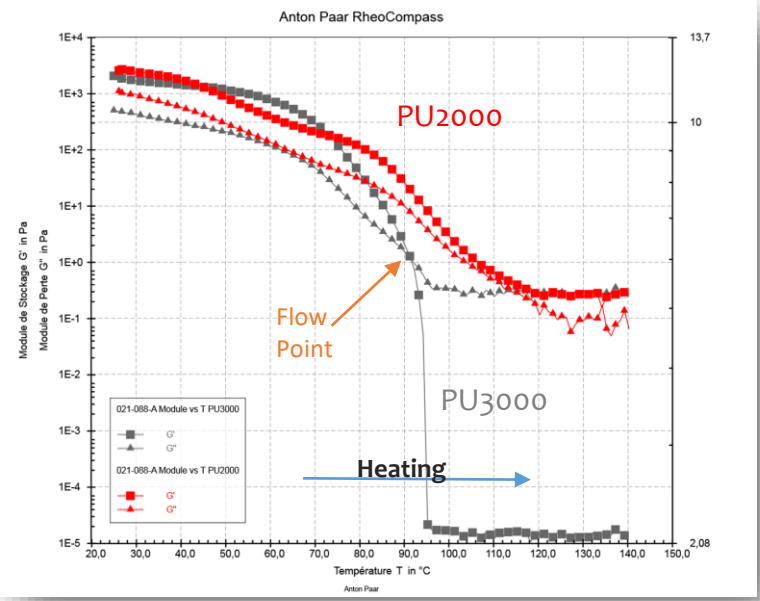
Key Targets
$\eta 10s^{-1}$: 40 ± 10 Pa. s
$\eta 100s^{-1}$: 6 ± 2 Pa. s
TML <1%

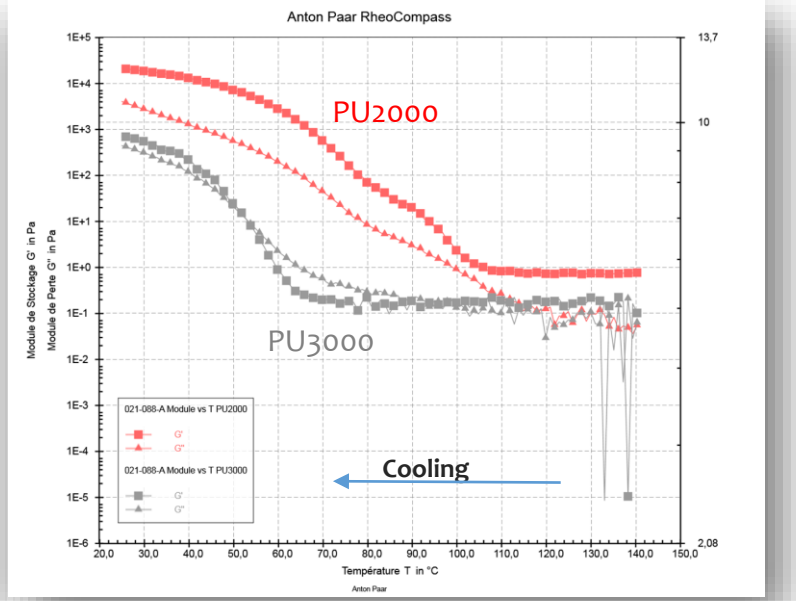
High Mn
PU3000

	PU2000 (90 %wt NYE2001A – 10 wt% PU2000)		
	Viscosité $10s^{-1}$	**Viscosité $100s^{-1}$**	**TML**
Batch N°1 *(150 g)*	39 Pa.s	6 Pa.s	99.7 %
Batch N°2 *(165 g)*	37 Pa.s	6 Pa.s	99,7 %
Batch N°3 *(165 g)*	41 Pa.s	6 Pa.s	99.5 %

	PU3000 (91 %wt NYE2001A – 9 wt% PU3000)		
	Viscosité $10s^{-1}$	**Viscosité $100s^{-1}$**	**TML**
Batch N°1 *(160 g)*	45 Pa.s	6 Pa.s	99.9 %
Batch N°2 *(170 g)*	46 Pa.s	7 Pa.s	100 %
Batch N°3 *(170 g)*	40 Pa.s	6 Pa.s	99.8 %

- Rheological behavior (temperature)





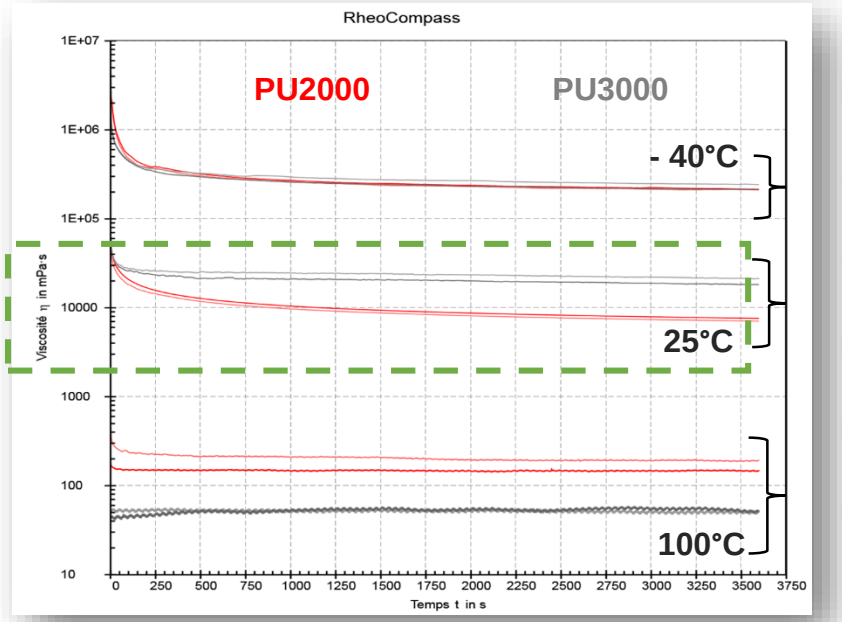
- ✓ Flow point PU2000 > PU3000
- ✓ Stucture recovery on cooling for the two gels
  - Slower recovery speed and less "firm" structure (lower G* modulus) for PU3000

- Other properties

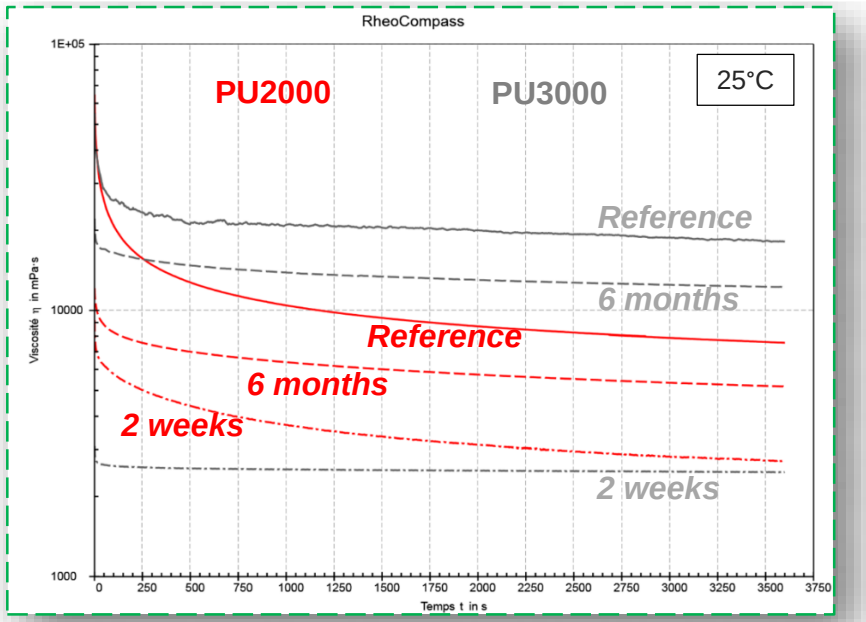
Sample reference	Evaporation loss 22h/121°C (%w/w)	Dropping point(°C)	Apparent density
PU2000 CRG 20160	< 0,1	94	0,83
PU3000 CRG 20161	To be confirmed	88	0,80
Space grease	< 0,1	160-220	< 1

- ✓ Evaporation loss < 0.1% for PU2000 gel, equivalent to space grease
- ✓ Low dropping point compared to a grease ➔ Limited application at high temperature?
- ✓ Relatively low density ➔ Interesting property for mass gain in bearings

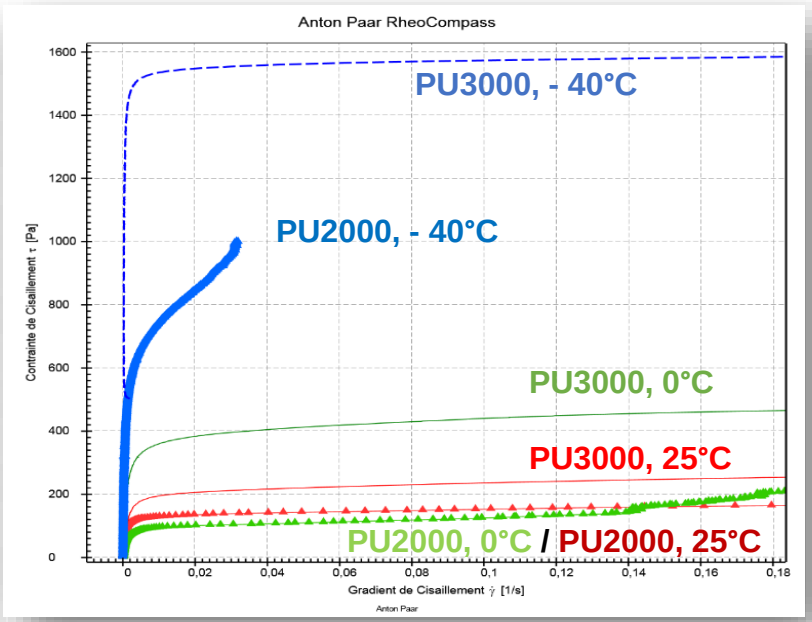
- Rheological behavior (shear)



- ✓ Dynamic viscosity PU3000 > PU2000 at 25°C but inversely at 100°C (related to flow temperature)
- ✓ Gelled oils are sensitive to shear stress ➔ Shear-thinning behavior for both gels



- ✓ Initial dynamic viscosity not restored 6 months after "grease worker" shear whatever the gel ➔ Weak thixotropic effect (too high shear, test for grease)
- ✓ Thixotropy PU2000 > PU3000
- ✓ Shear strength PU2000 > PU3000



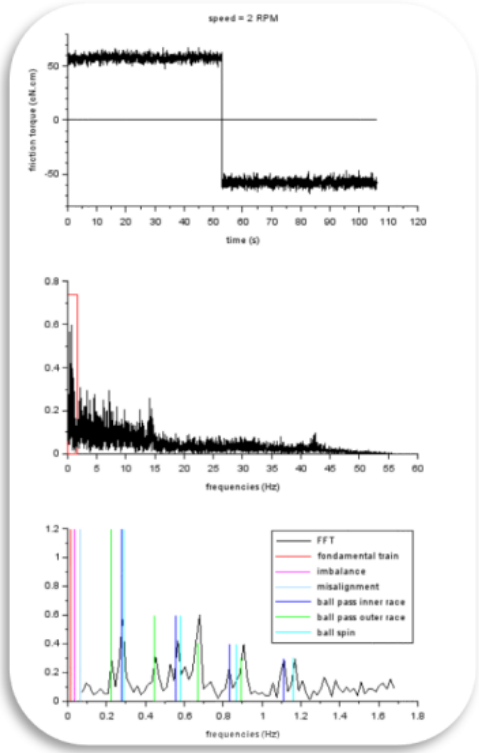
- ✓ Both gels are stress threshold fluids
- ✓ Flow stress PU3000 > PU2000 whatever the temperature (-40°C, 0°C and 25°C)

- Behavior in a ball bearing* (tests on ADR-ALCEN bench)

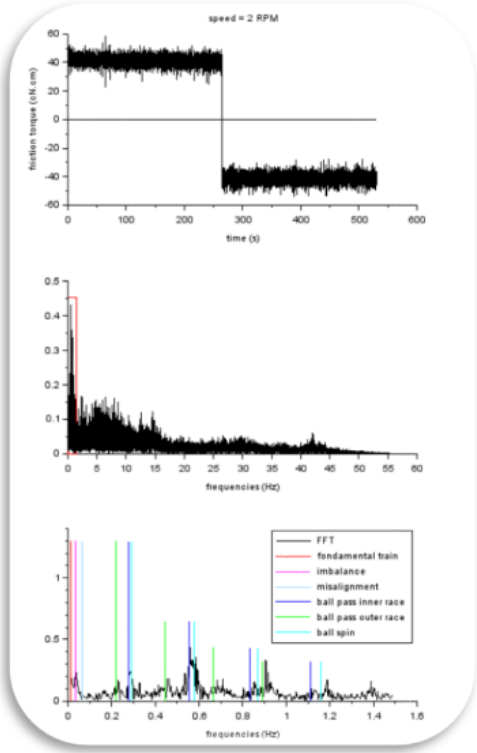
✓ Same behaviors for the two gels

✓ Low and stable rolling torques (torques twice lower than classical space greases 50 cN.cm instead of 100 cN.cm):
  - Grease behavior for location near the contact
  - Oil behavior for torques

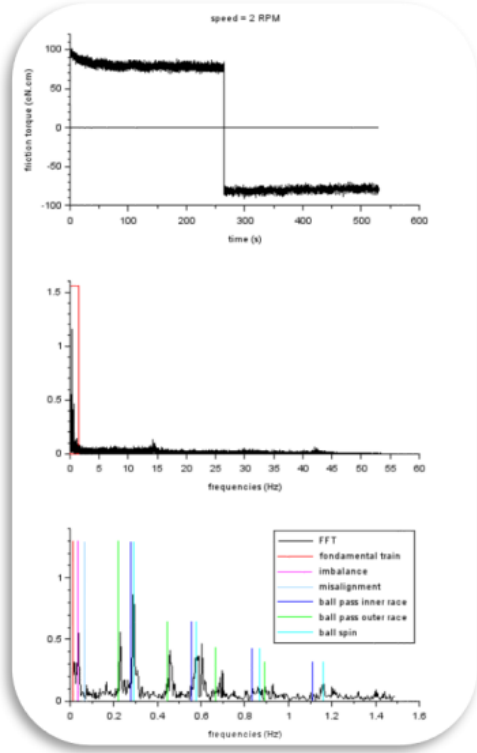
✓ Frequency analysis :
  - Same characteristic frequencies but intensity lower for gels, like oil only.
  - Bearing defaults increased by classical space grease (PTFE aggregate ?)



Oil only
Cm = 58 cN.cm, %N = 9.0



Gelled oil grease
Cm = 41 cN.cm, %N = 14

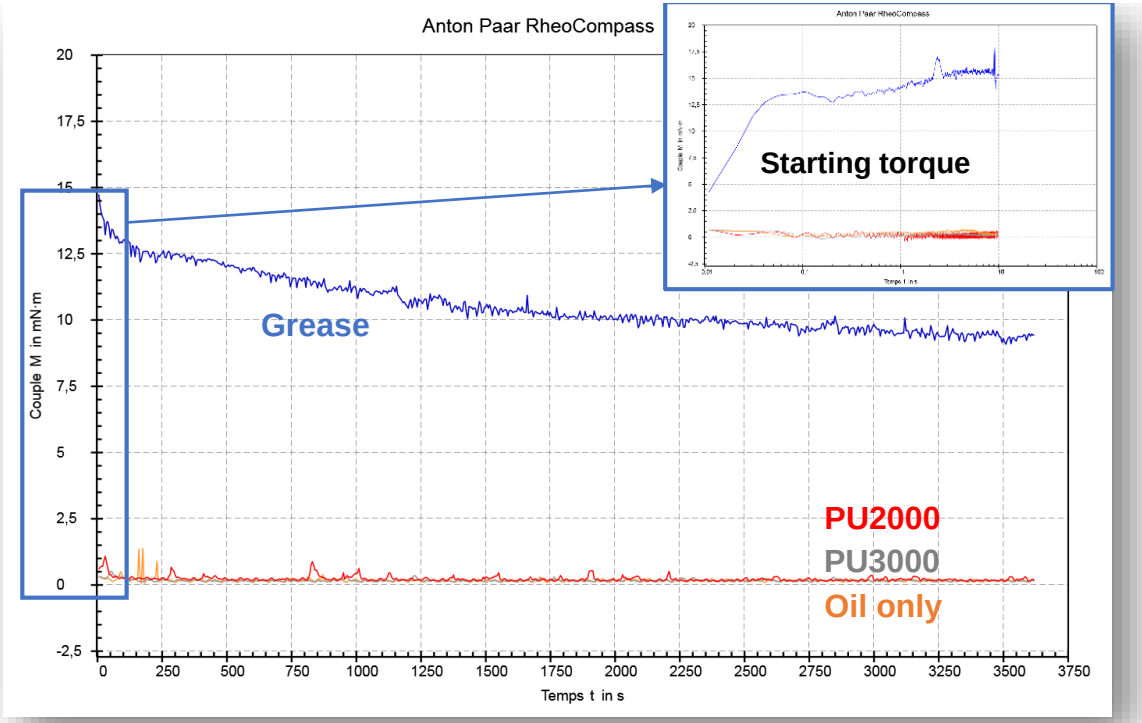


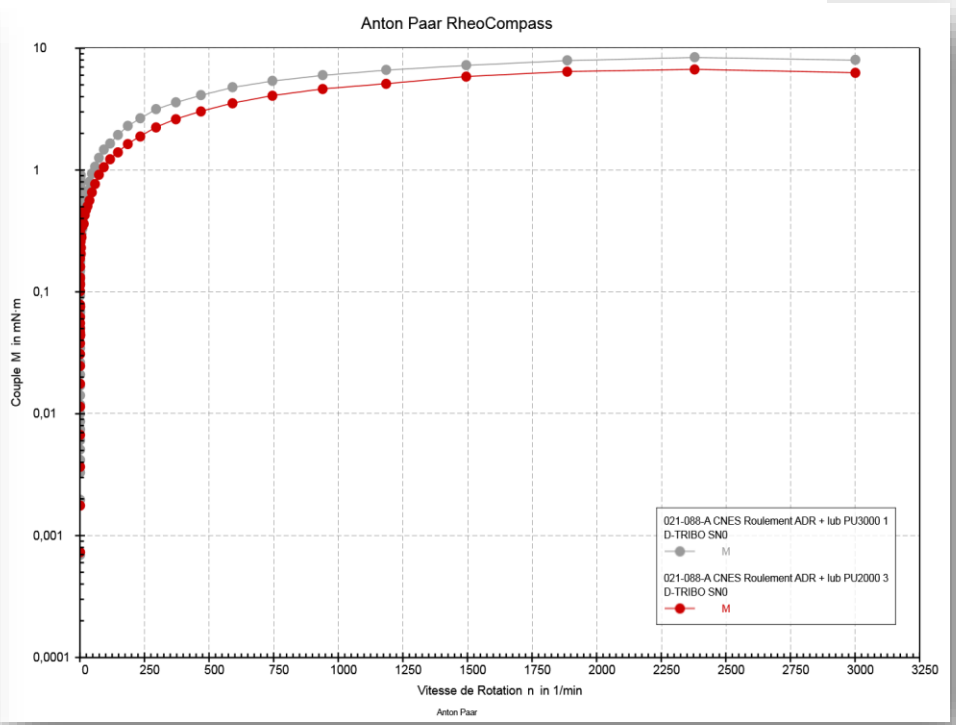
Classical space grease
Cm = 80 cN.cm, %N = 10

ADR ALCEN

*Full results presented at ESMAT 2021

- Behavior in a ball bearing (InS tests on a rheometer)





- ✓ Same behavior for the 2 gelled oil references, with low rolling torque, identical to the base oil alone and much lower than a grease*
- ✓ Rolling torque stabilization (< 10 mN.m) at high rotation speed
- ✓ Similarity in the range of measured torques between the two test benches (ADR/InS)

*PFPE / PTFE grease, bearing 6204

TRIBOLOGICAL TESTS ON HV TRIBOMETER

- 3 lubricants :
  - 2 gelled oils : PU2000 & PU3000
  - 1 grease for reference (Maplub pf100-b)

- 1 Hertz contact pressure : 1 GPa

	Kinematics	
	Continuous	Oscillating
Pure sliding	10 mm/s	10 mm/s
	225 mm/s	210 mm/s
Rolling with sliding	10 mm/s ; SRR = 10%	10 mm/s ; SRR = 10%
	125 mm/s ; SRR = 10%	125 mm/s ; SRR = 10%

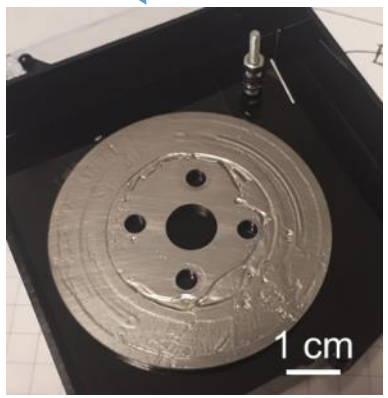
  - 1000 cycles @ 225mm/s, 125 mm/s,
  - 100 cycles @ 10 mm/s

- Environment : high vacuum 4.10^{-7} mbar

TRIBOLOGICAL TESTS ON HV TRIBOMETER

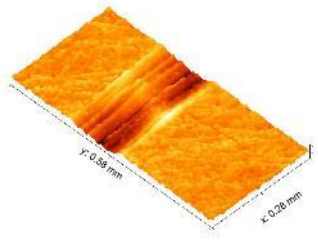
▲ *Calibrated thickness of 100µm*

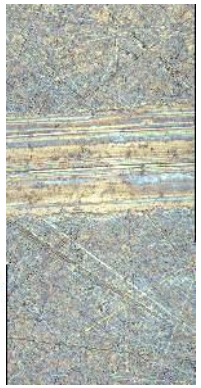
Friction test



Sample cleaning

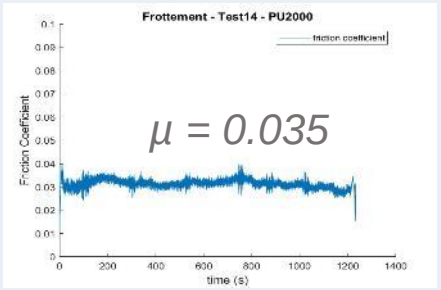
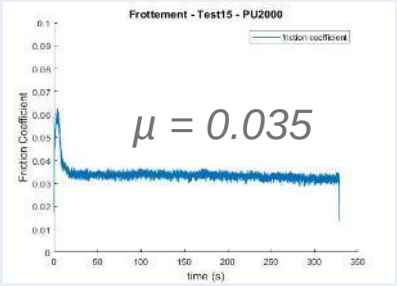
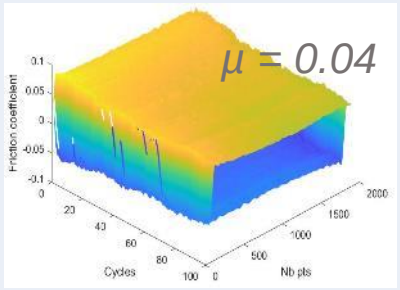
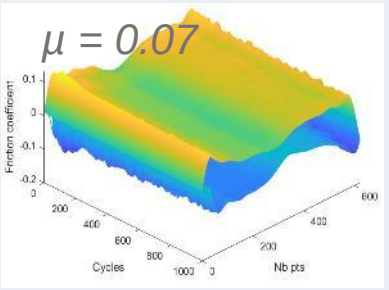
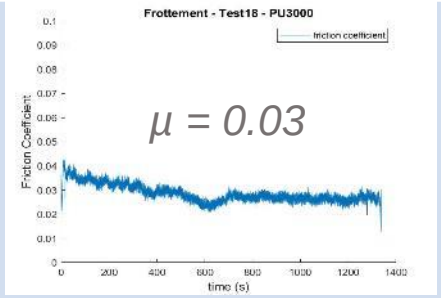
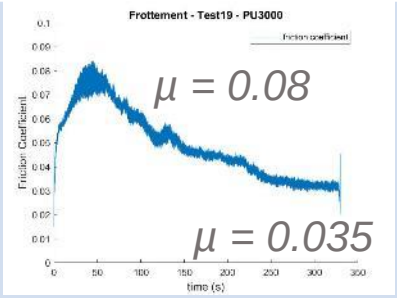
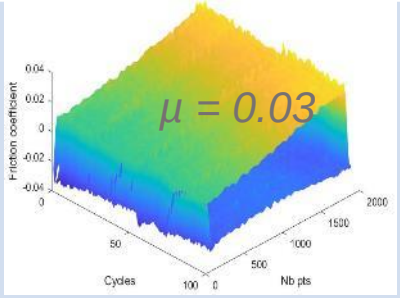
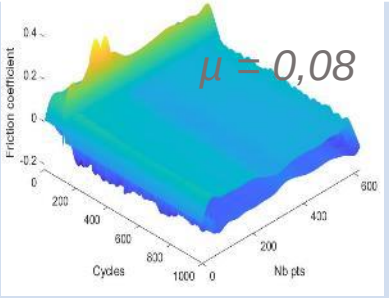
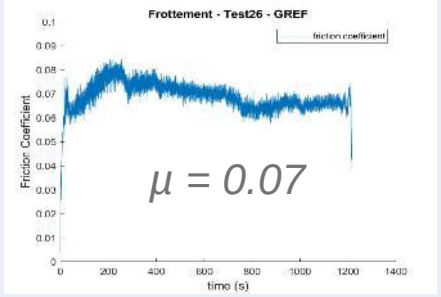
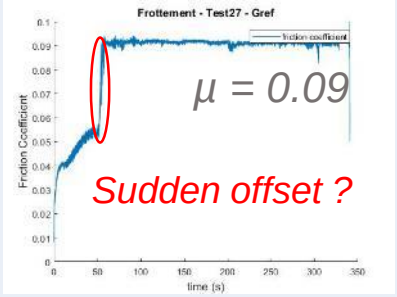
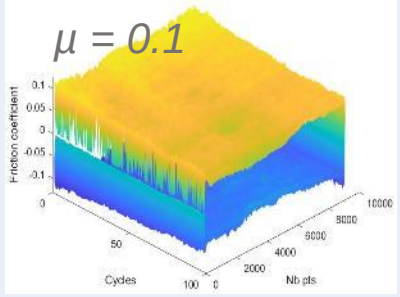
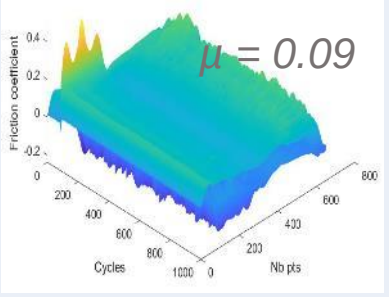
Topography and surface morphologies





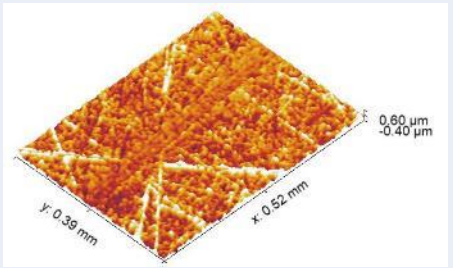
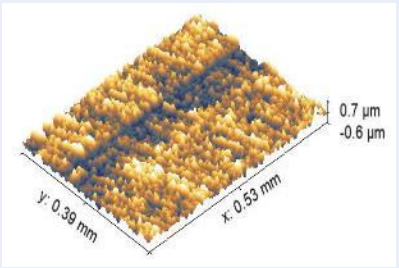
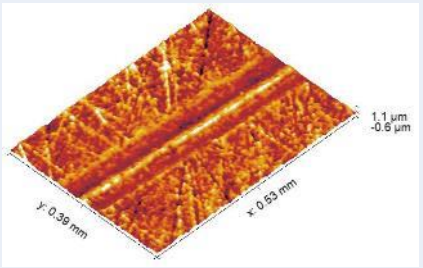
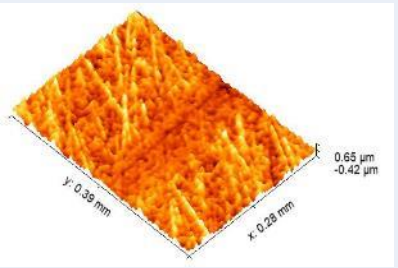
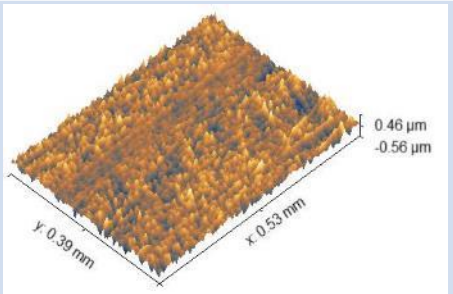
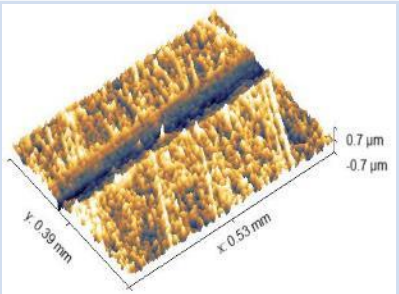
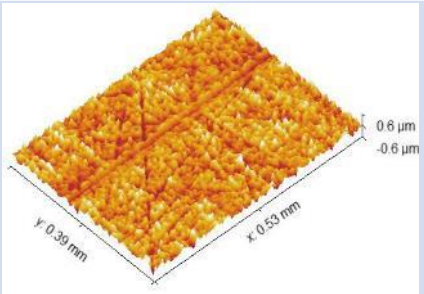
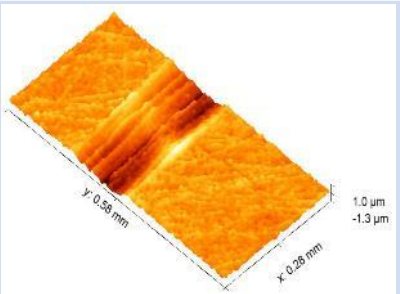
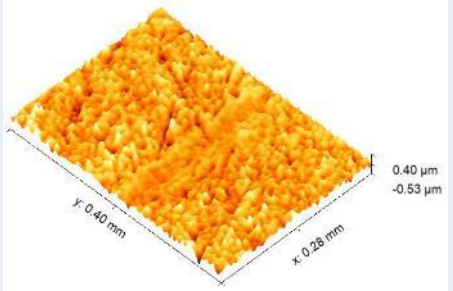
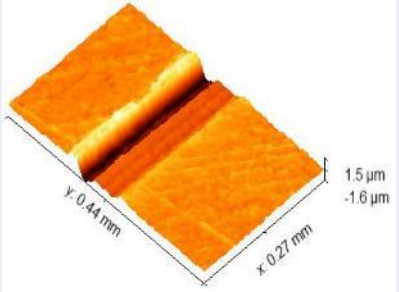
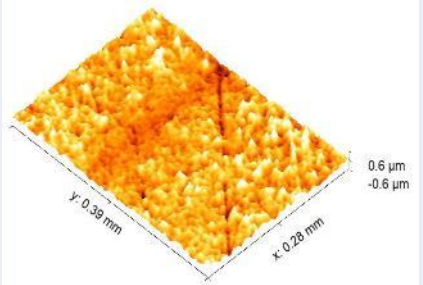
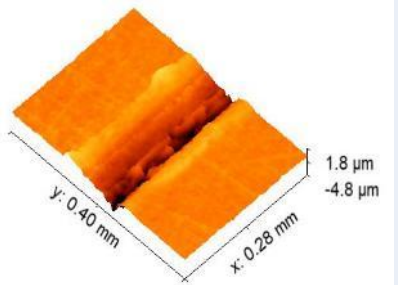
TRIBOLOGICAL TESTS ON HV TRIBOMETER - *RESULTS*

Pure sliding tests

	Continuous sliding		Oscillating	
	10 mm/s	225 mm/s	10 mm/s	210 mm/s
PU2000				
PU3000				
Maplub pf-100 b				

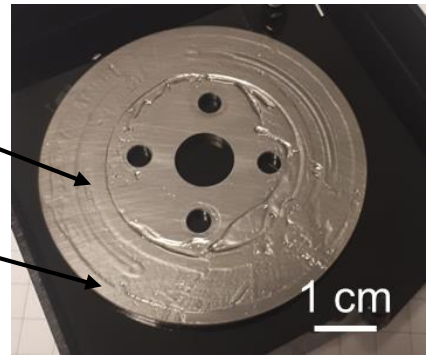
TRIBOLOGICAL TESTS ON HV TRIBOMETER - *RESULTS*

Surface topography

	Continuous sliding		Oscillating	
	10 mm/s	225 mm/s	10 mm/s	210 mm/s
PU2000				
PU3000				
Maplub pf-100 b				

Conclusion

- ✓ **Two gelled hydrocarbon oils** (Multi-Alkyl Cyclopentane) **are obtained** (PU2000, medium Mn ; PU3000 high Mn)
- ✓ **Shear thinning behavior** favorable to dynamic bleeding
- ✓ Comfortable operating temperature range at first approach (-40°C → +140°C)
- ✓ Stable behavior with **low torque in ball bearing** operation with no friction peak compared to classic space grease
- ✓ Tribological tests allowed to discriminate gelled oils and the reference grease :
  - PU2000 > PU3000 >> Maplub pf100-b
  - **Very good antiwear behavior** and better refill of the contact with PU2000
  - No lateral ejection of gelled oil on the disc



✓ **Hybrid technology as an alternative to classic space greases**

- Continuation of activities

✓ ORO Test on rheometer to confirm good thixotropic behavior

✓ Vacuum endurance in bearings (RAMI bearing box) to study **stability and durability**

- InS tribometer, linear and rotary motor with multi-couplings possible, 10^{-7} torr, max. 200N, max. 4,6 N/m, max. 1800 rpm, [-150°C ; +400°C]

✓ Rolling/sliding tests with SRR 10% @ FEMTO-ST

✓ Industrialization

- Pilot-scale validation
- Technology transfer

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