stle Nashville
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IDEMITSU

Simulation of Grease Flow in Speed Reducer of Robot

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5/23/2019 at Nashville, U.S.A.

1. Introduction

Speed Reducers for Robots

Planetary Differential Gear (RV Gear)

Ball Bearing, Needle Bearing, Taper Roller Bearing, Spar Gear, Pin Gear

Strain Wave Generator (Harmonic Drive)

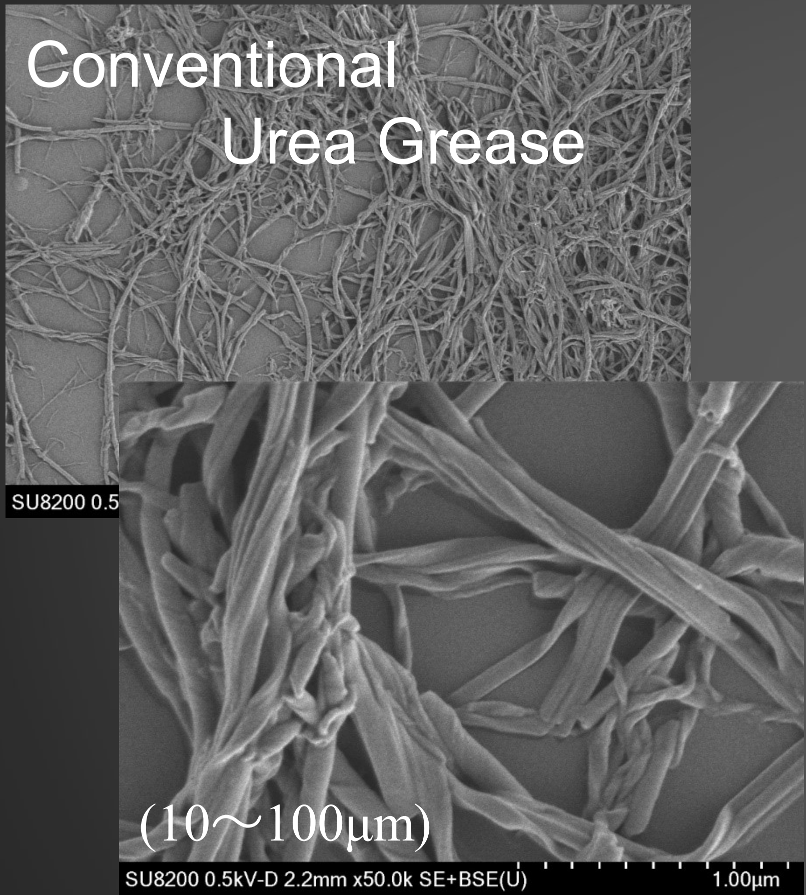
Ball Bearing (Wave Generator), Cross Roller Bearing, Flexspline, Circular Spline

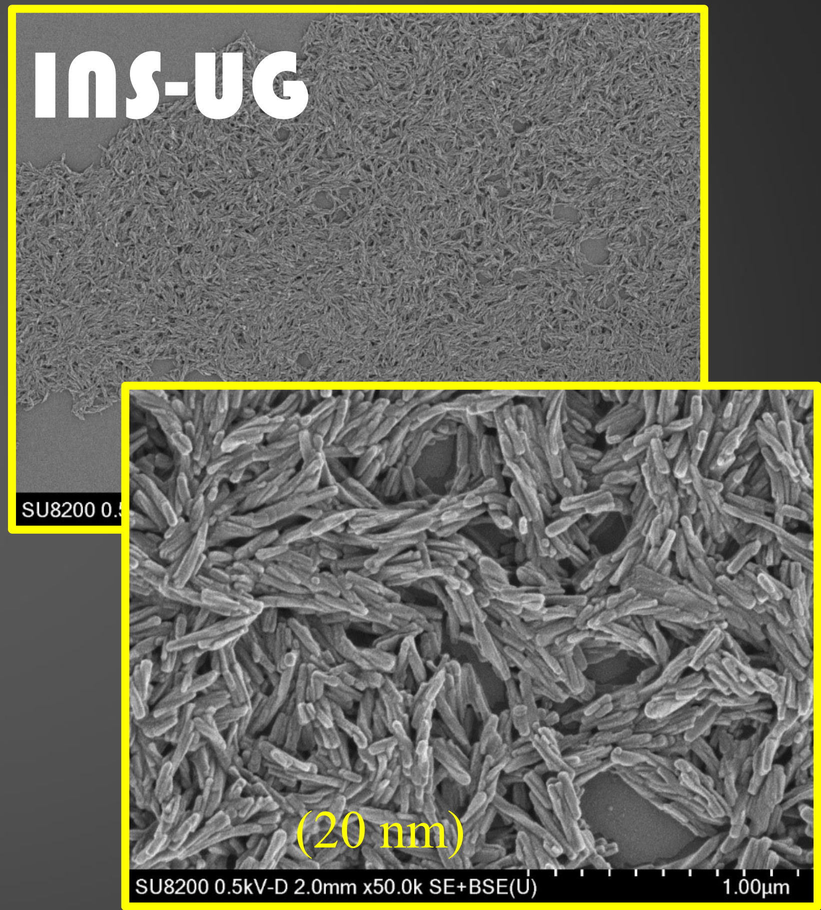
Inscribed Planetary Gear (Cyclo Gear)

Ball Bearing, Needle Bearing, Pin Gear

1. Introduction

Previous Study (2018) : Nano Structure Urea Grease





SEM Photograph of Thickener Fiber (Aliphatic di-Urea)

1. Introduction

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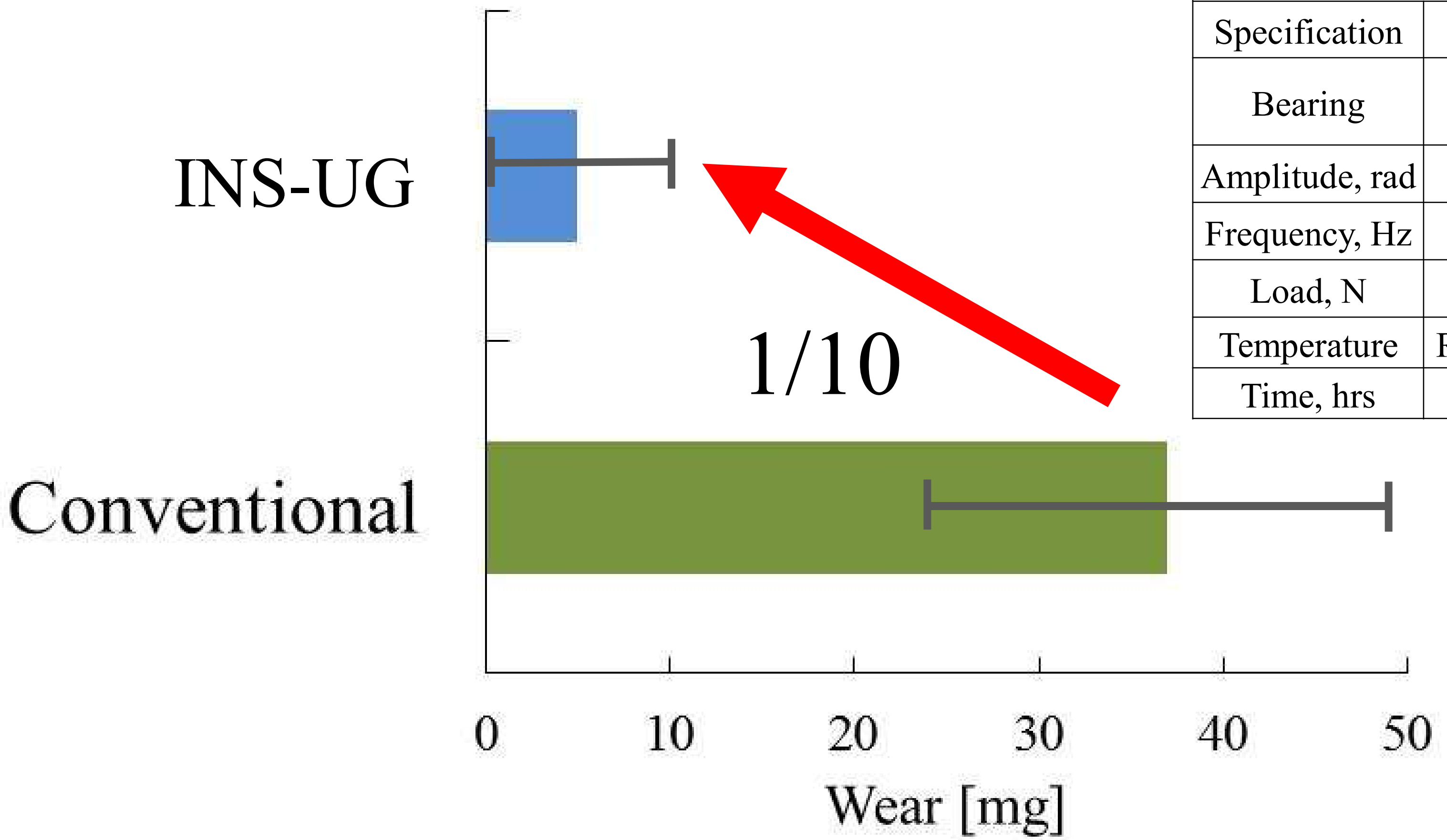
Performance of INS-UG

Characteristics		INS-UG	Conventional	Evaluation
Noise	Be Quiet [-]	GN4	GN1	◎
Anti-Weld	FALEX [N]	1050	700	◎
Fretting Wear	ASTM D 4170 [mg]	4	37	◎
Durability	ASTM D 3336 [h]	2256	1181	◎
Low Temp. Property	Yield Stress @-20℃ [Pa]	2500	5500	◎
Heat Resistance	Dropping Point [℃]	260<	260<	○
Rust Prevention	Bearing Rust Prevention [-]	Pass	Pass	○
Water Resistance	ASTM D1264 [wt%]	0.1	0	○
Shear Stability	Roll Stability @80℃, 20h [-]	46	55	○
SHELL EP	ASTM D2783 WL [N]	1236	1236	○
SHELL Wear	ASTM D2783 [mm]	0.48	0.53	○

1. Introduction

Previous Study (2018) : Fretting Wear Property (ASTM D 4170)



Fretting wear test	
Specification	ASTM D4170
Bearing	Thrust bearing 51203
Amplitude, rad	±0.105
Frequency, Hz	25
Load, N	2940
Temperature	Room temperature
Time, hrs	22

1. Introduction

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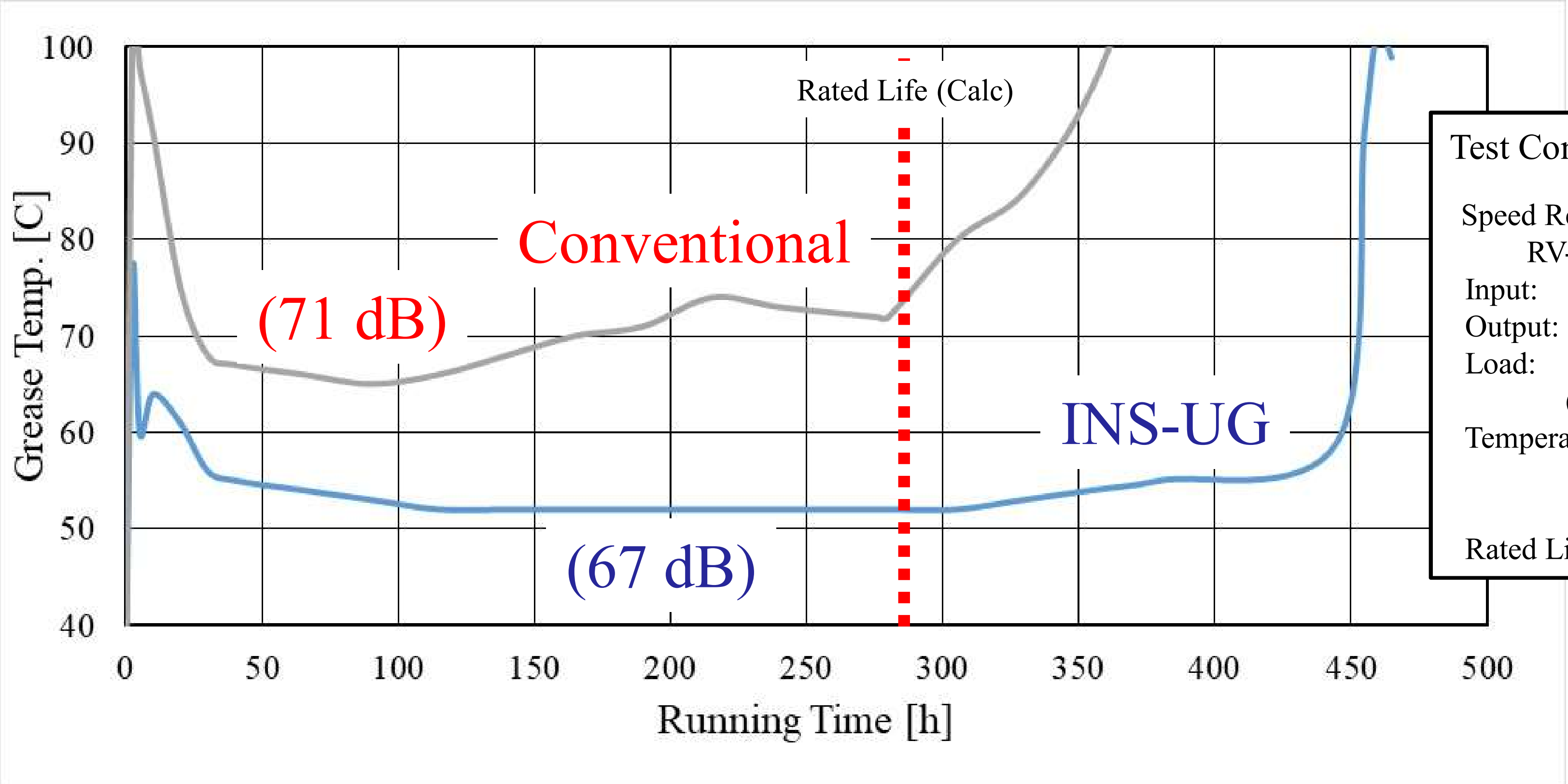
Previous Study (2018) : Durability Test (RV Gear)



Test Conditions

Speed Reducer: RV-42N (Nabtesco)
Input: 2015 rpm
Output: 15 rpm
Load: 1030 Nm (Rated: 412 Nm)
Temperature: No Control

Rated Life (calc.): 283 h

Nano Structure → Low Power Loss → Low Heat Generation → Long Running Time

2. Simulation

Purpose of Simulation Study:

By simulating the flow properties and conditions of grease,

1) Visualize grease flow in gear box
   → Easy-to-understand grease performances

2) Predict the mechanism of grease lubrication by coupling with mesoscopic simulation
   → Design grease product
   → Design evaluation technique
   → Determine experimental condition range

By creating a database of grease products (unique calculation subroutines and parameters) to improve simulation accuracy,

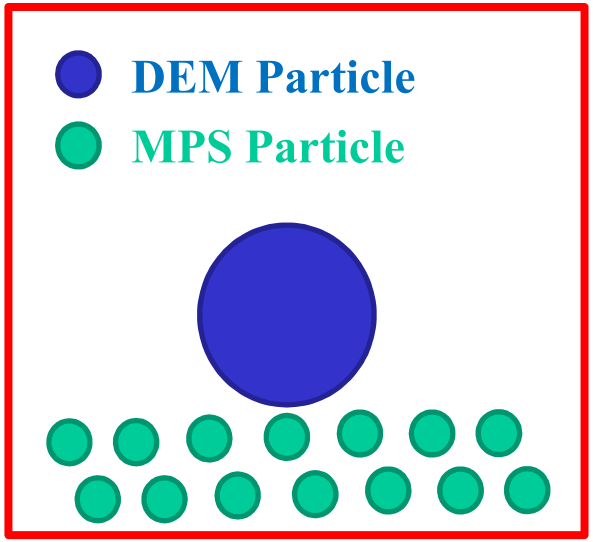
→ Application to machine design
→ Application to management of grease lubrication

2. Simulation

YEAR	STLE Presentation	Grease Flow Simulation
2015		Application of FEM, CFD, MPS
2016		
2017	Zero Leak Grease for Speed Reduced Gear of Robots	Application of DEM-MPS - Tackiness Tester -
2018	Nano Structure Urea Grease: Performance and Application	Application of MPS - Spar Gear (RV Gear) -
2019	Simulation of Grease Flow in Speed Reducer of Robot	Application of MPS - Cyclo Speed Reducer -

DEM-MPS Coupling Method

DEM (Discrete Element Method)
MPS (Moving Particle Semi-implicit)



Mass Conservation: $\frac{D\rho}{Dt} = -\rho \nabla \cdot \nu$

Momentum Conservation: $\frac{D\nu}{Dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2 + g + \frac{1}{\rho}F_s$

Gradient Model: $< \nabla \nu >_i = \frac{d}{n_0}\sum_{j \neq i}\left[\frac{\nu_j - \nu_i}{r^2 ij} r_{ij} w_{ij}\right]$

Laplacian Model: $< \nabla^2 \nu >_i = \frac{2d}{n_0 \lambda}\sum_{j \neq i}\left[(\nu_j - \nu_i) w_{ij}\right]$

Particle Number Density: $n_i = \sum_i w_{ij}$

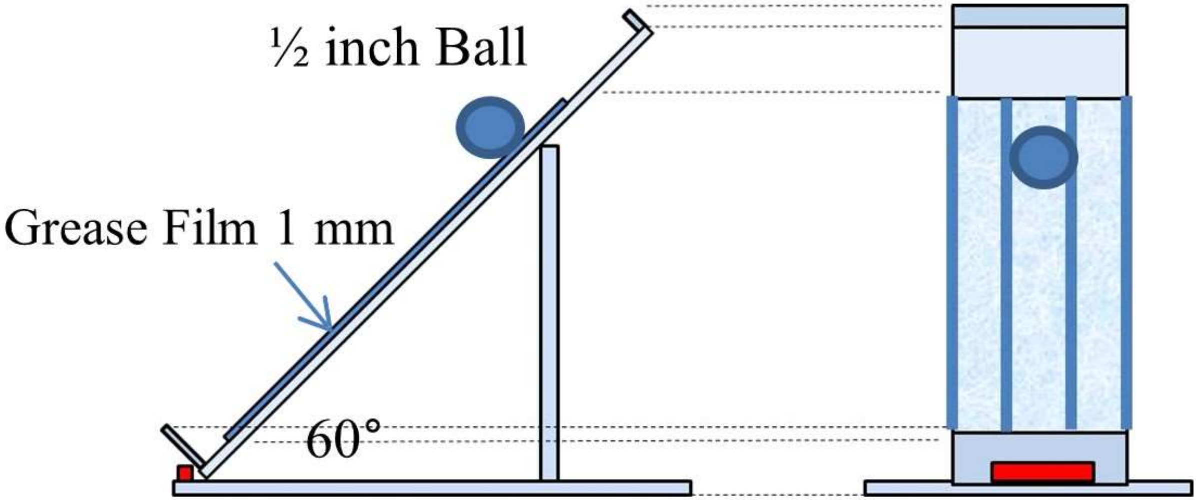
Weighting Function: $w_{ij} = \frac{r_e}{r_{ij}} - 1 \quad (r_{ij} \leq r_e), \qquad 0 \quad (r_{ij} > r_e)$

Correction Factor: $\lambda = \frac{\sum_{j \neq i}(w_{ij} r_{ij} 2)}{\sum_{j \neq i} w_{ij}}$

3. Simulation-1

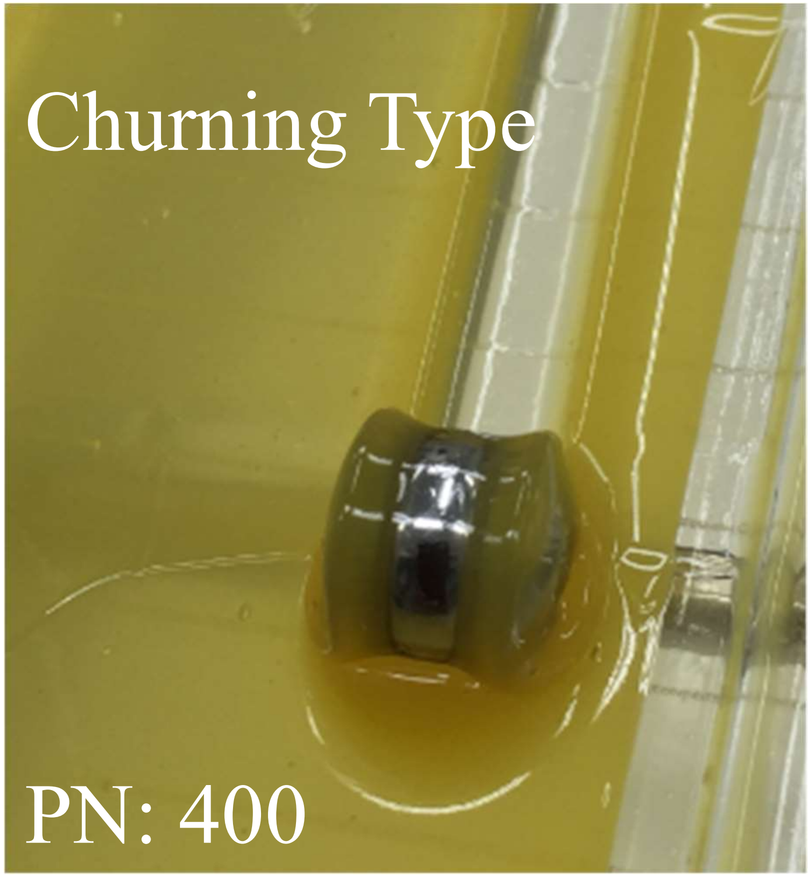
Simulation of Original Grease Tackiness Tester

- ◇ Time of Ball Fall
- ◇ Grease Adhesion to Ball → **Good Correlation** → ◇ Penetration, Torque Property
- ◇ Shape of Passing Mark



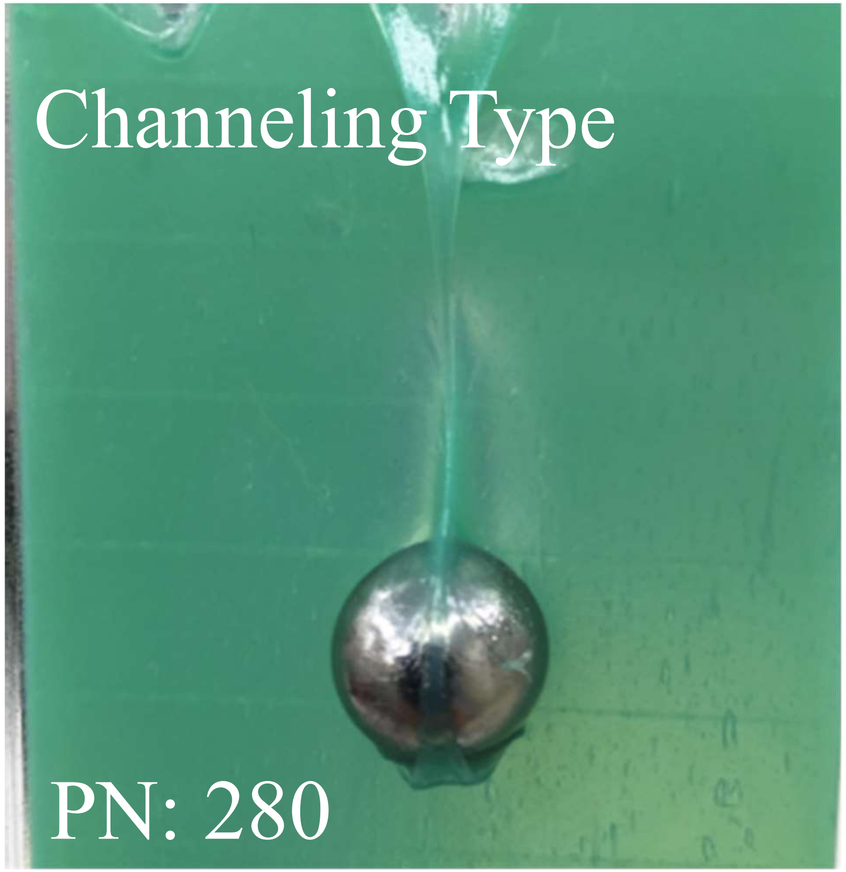
3. Simulation-1

Soft Grease



Two stripes on the ball
Passage mark: scraped off grease

Hard Grease



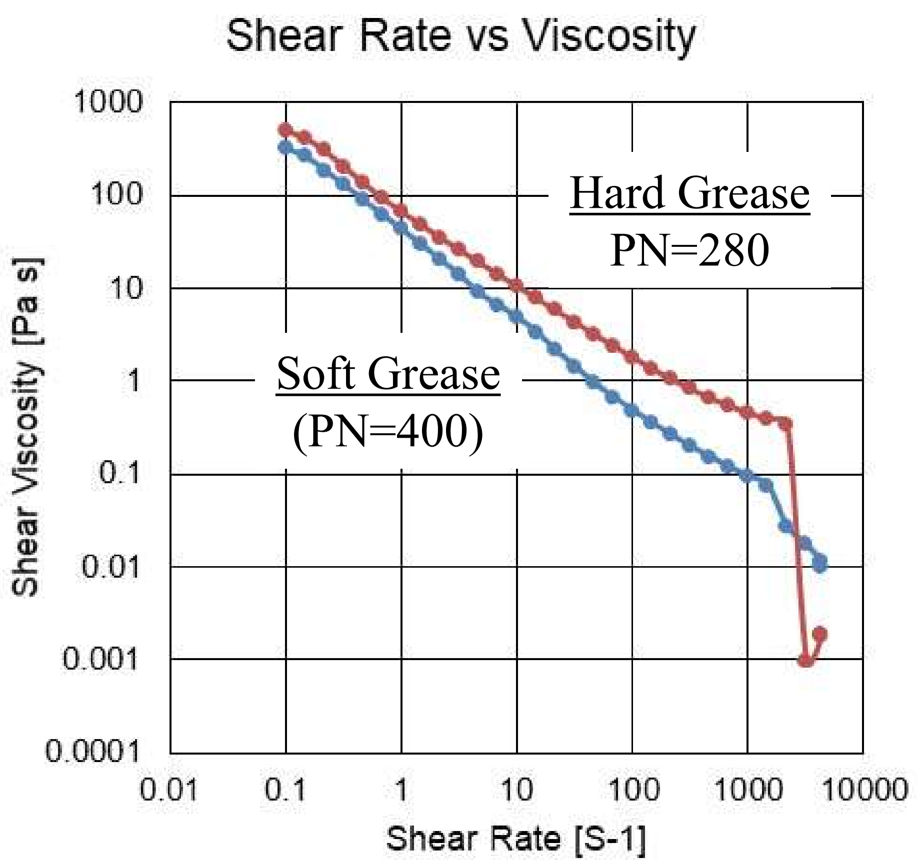
One stripe on the ball
Passage mark: unclear

3. Simulation-1

Calculation Conditions

<DEM>
Ball Diameter: 12.6 mm
Ball Density: 6132 kg/m^3
Spring Const.: 20000 N/m
Restitution Coeff.: 0.1
Friction Coeff.: 0.3
Δt = 0.025 msec

<MPS>
Particle Diameter: 0.25 mm
Density: 920 kg/m^3
Interfacial Tension: 0.023 N/m
Thickness: 1 mm
Number of Particle: 184,320
Δt = 0.25 msec

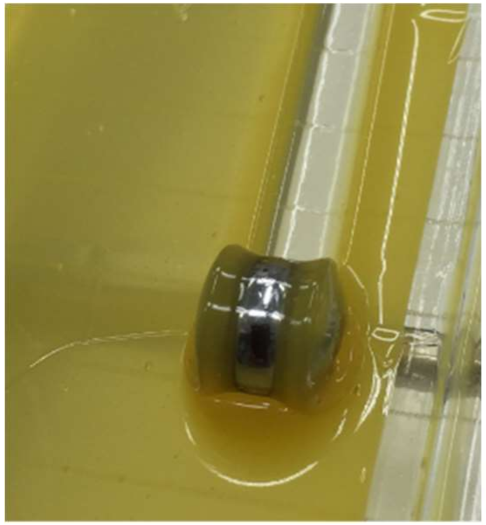


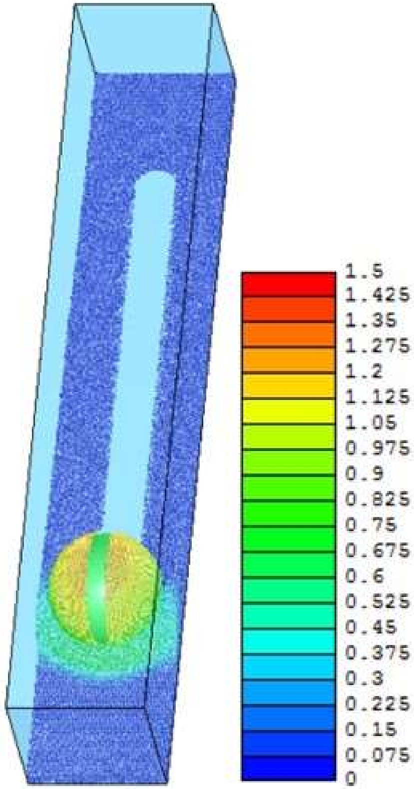
3. Simulation-1

Calculation Results

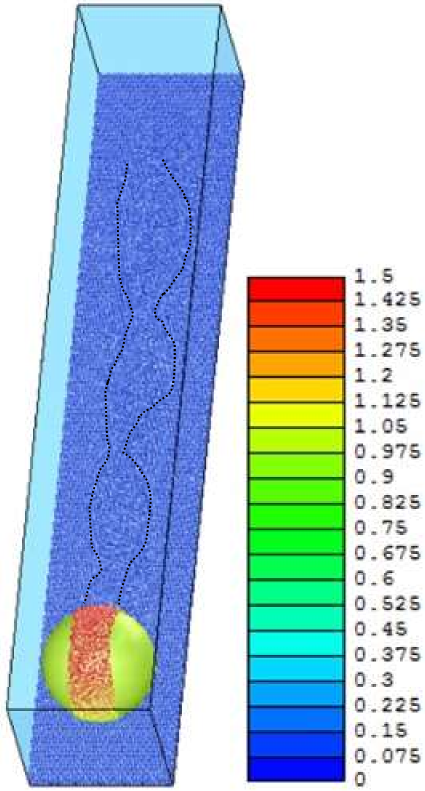
It was necessary to consider Non-Newtonian properties
(Shear rate dependence on apparent viscosity)

Soft Grease



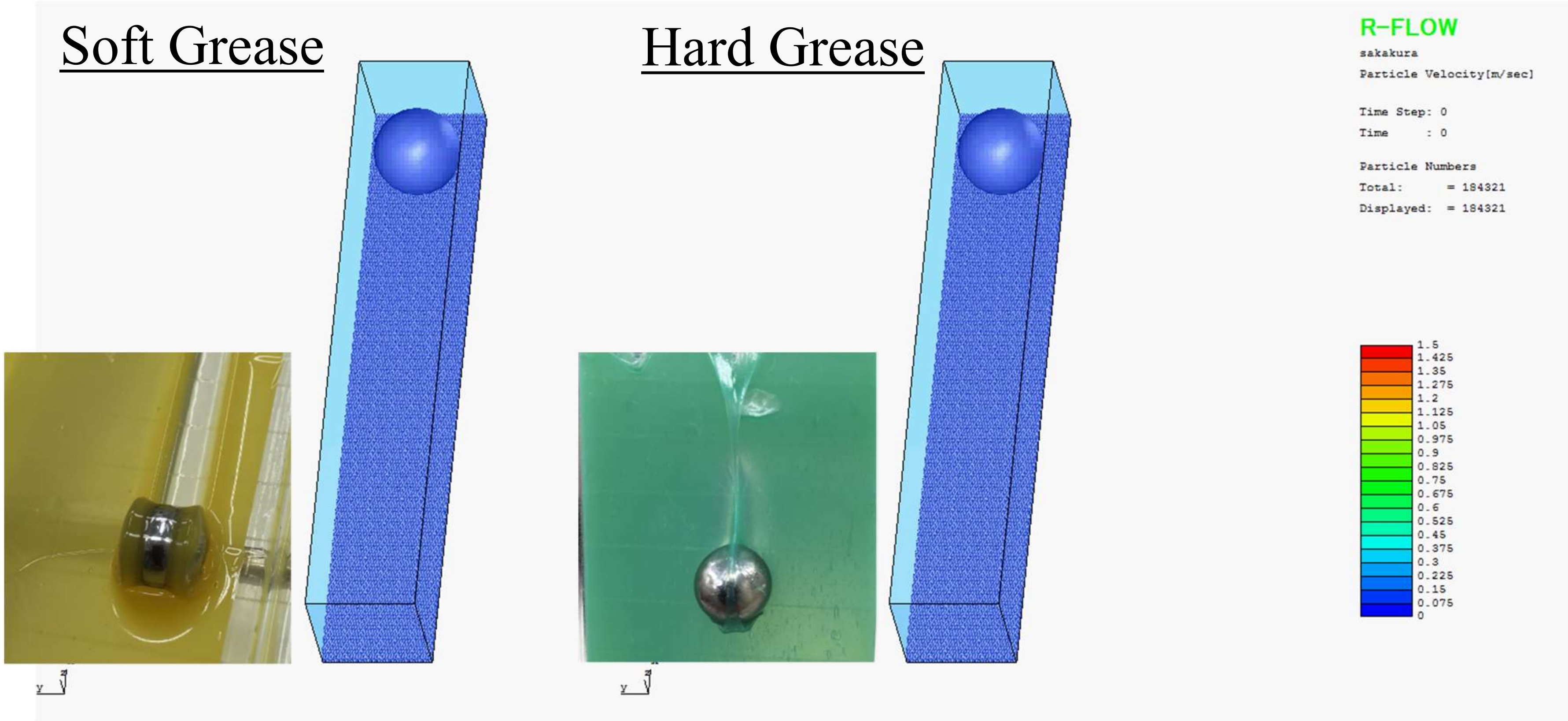


Hard Grease



3. Simulation-1

Calculation Results



RV GEAR

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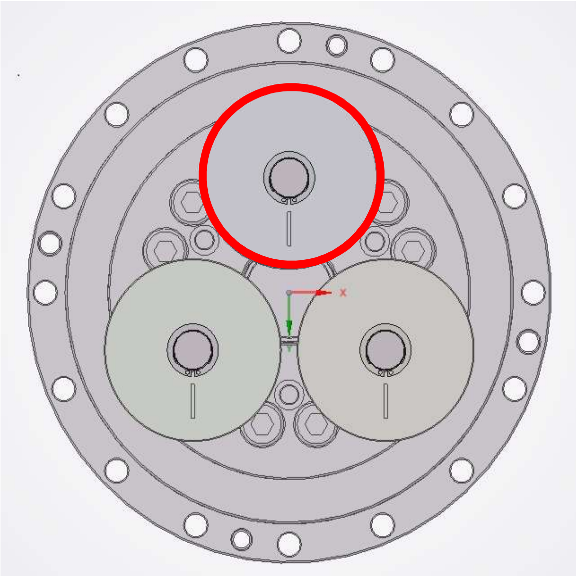
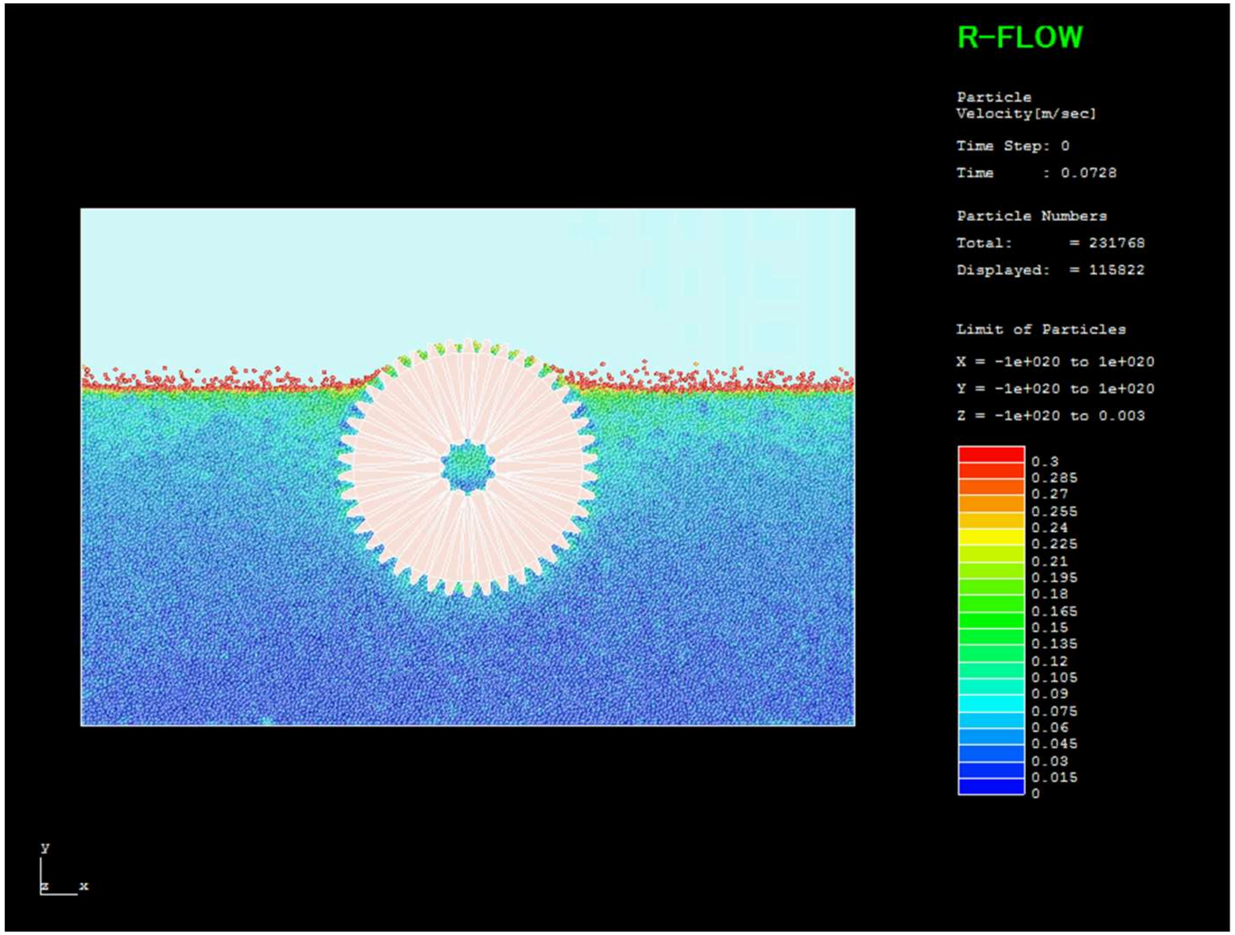
Calculation Result

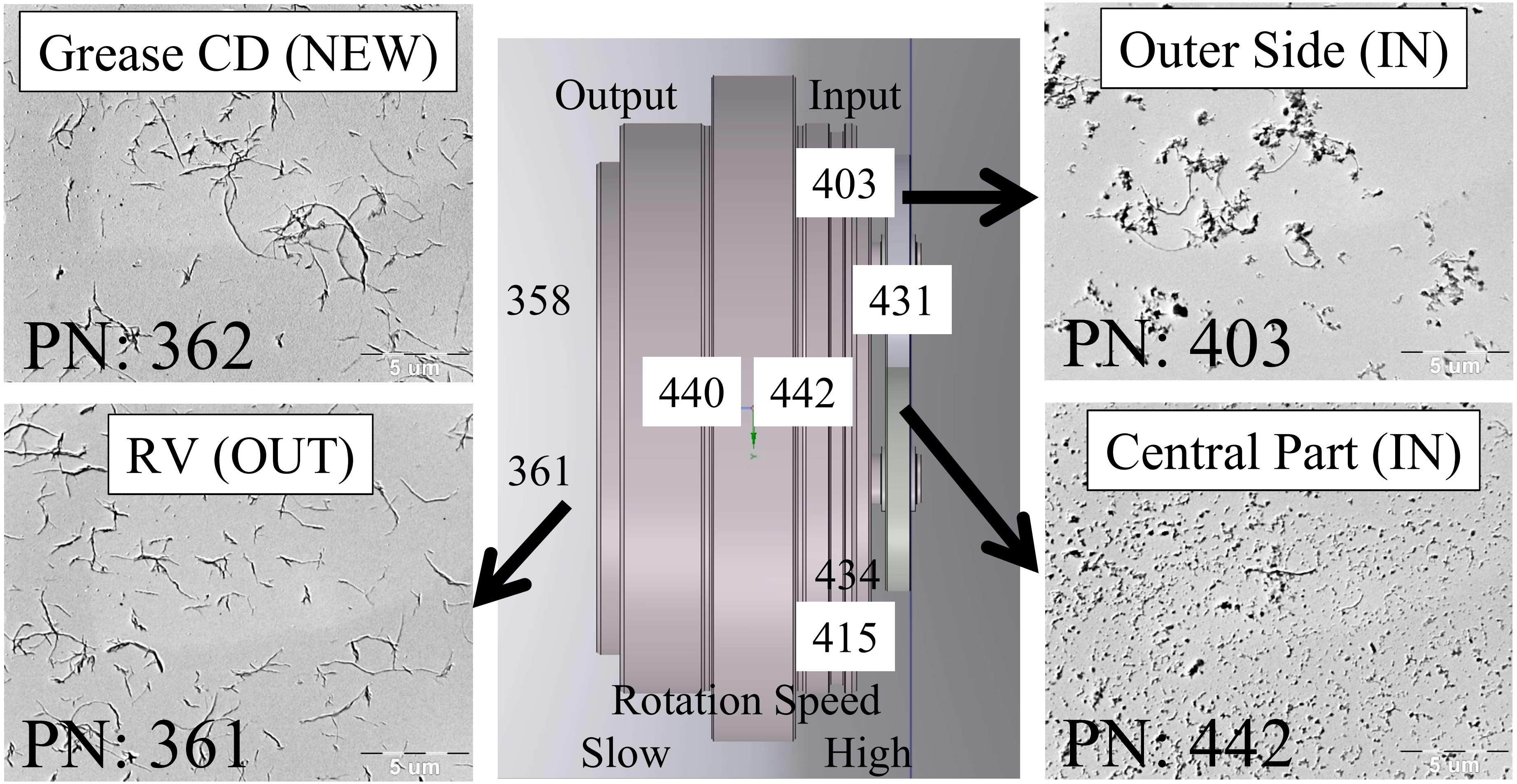




Simulation of Grease Flow around Spar Gear.

4. Simulation-2

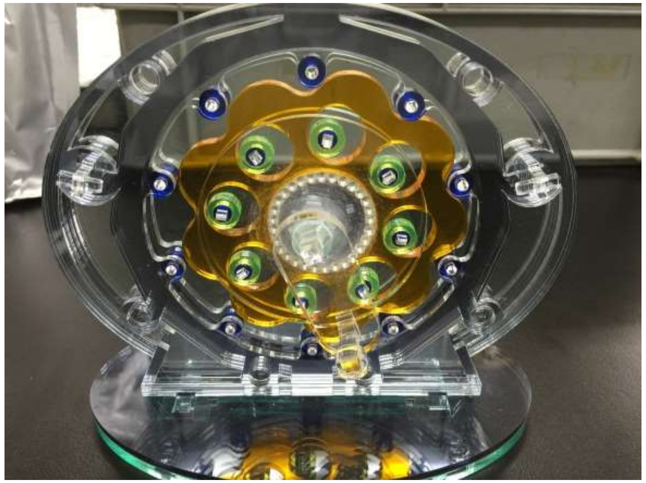
Penetration Distribution (Previous Results)

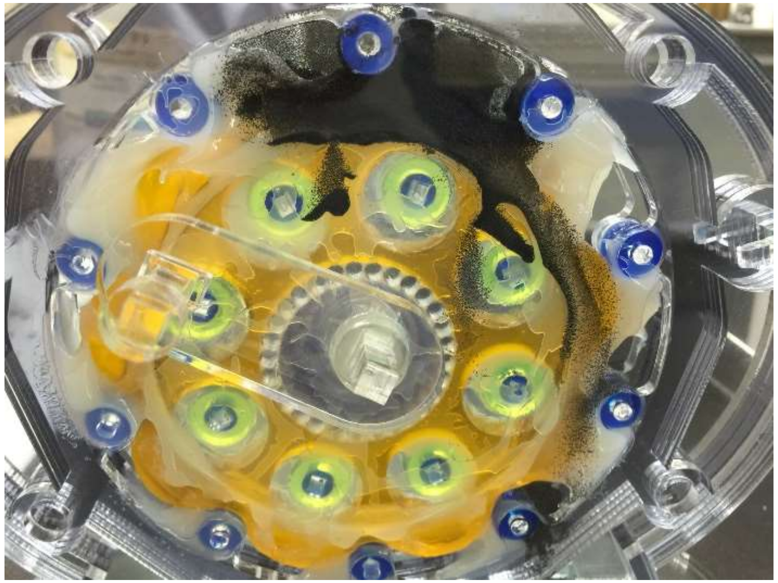


TEM Photographs of Recovered Greases after Durability Test.

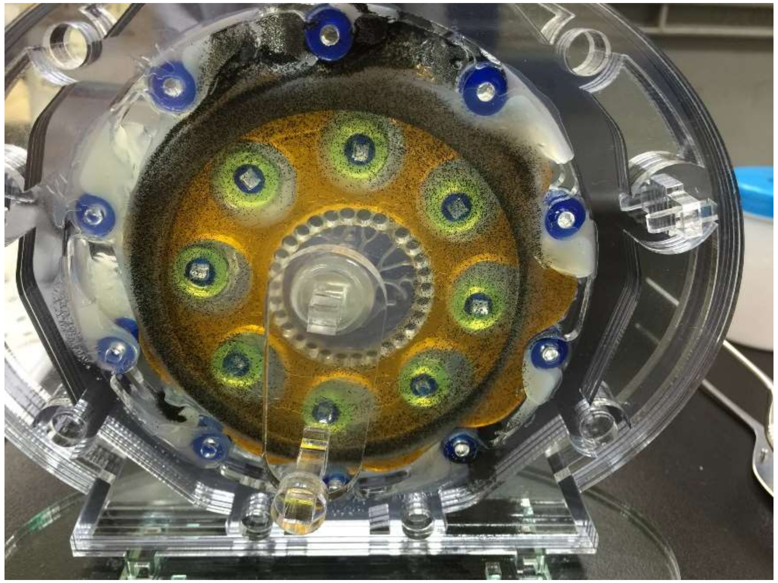
4. Simulation-2

Tracer Test: Cyclo Gear





Feed Carbon Black as a Tracer



After Rotation at 3 rpm (Output)

5. Simulation-3

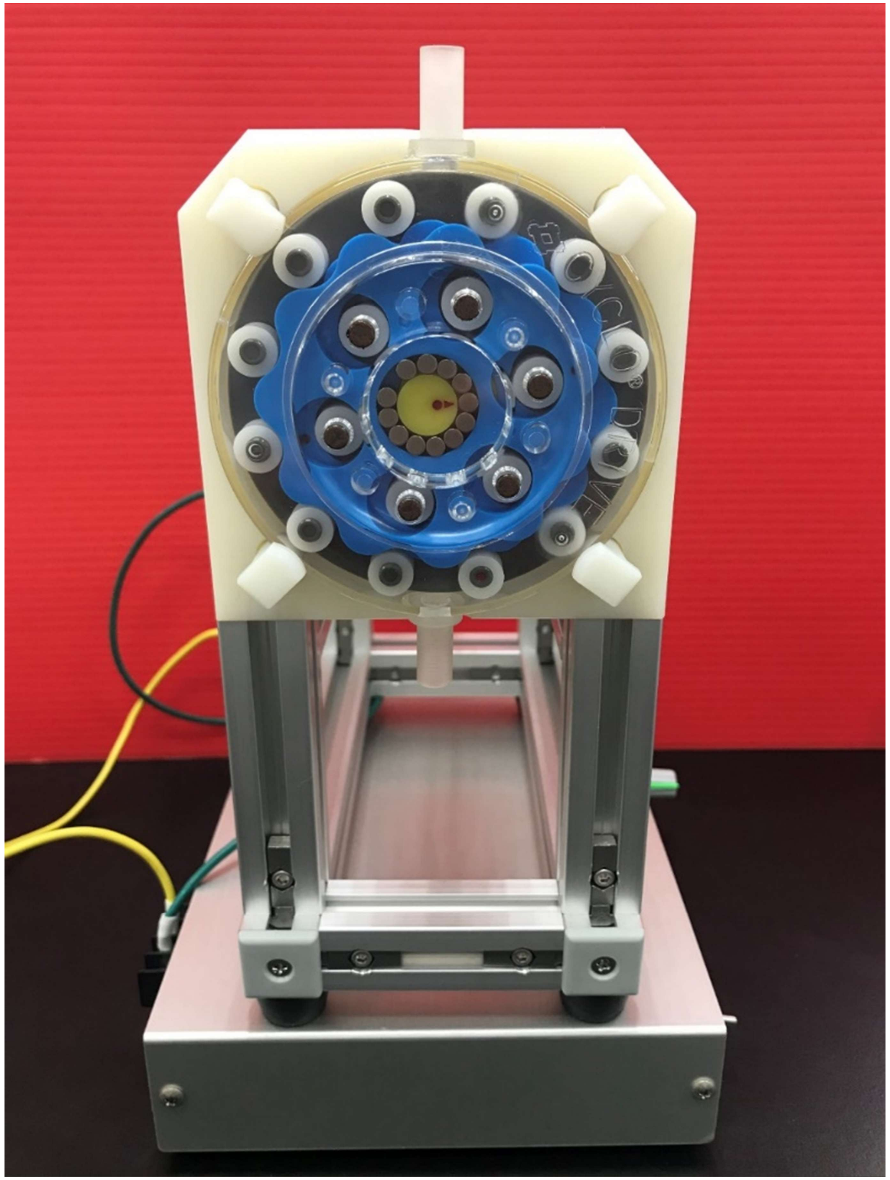
CYCLO GEAR MODEL

[Speed Reducer]

Gear: Acrylic-model of cyclo gear
(Sumitomo Heavy Industries, Ltd.)
Diameter: 88 mm
Type: 2 disc type
Gear ratio: 22
Filling volume: 14 ml

[Experiment]

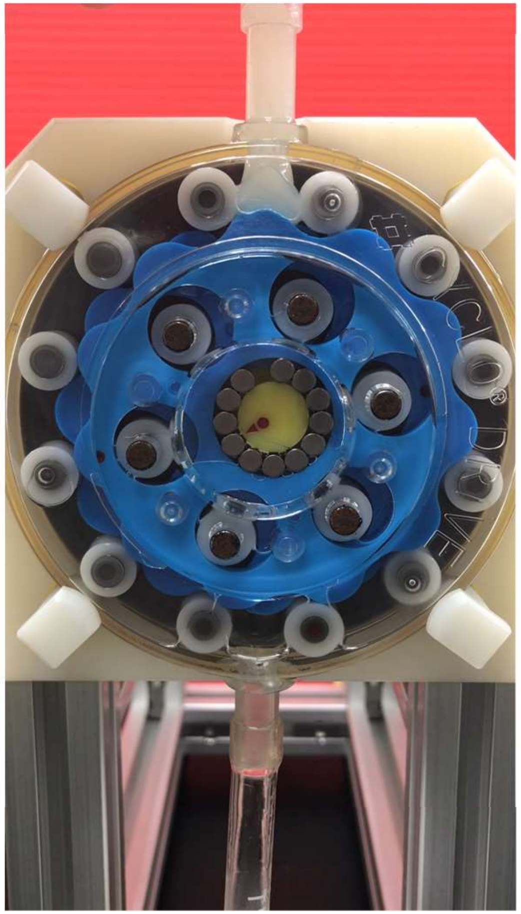
Test conditions: In: 60 rpm, Out: 2.73 rpm
Evaluation items:
- Grease flow
- Grease substitution rate
- Tracer (S compound) conc. distribution

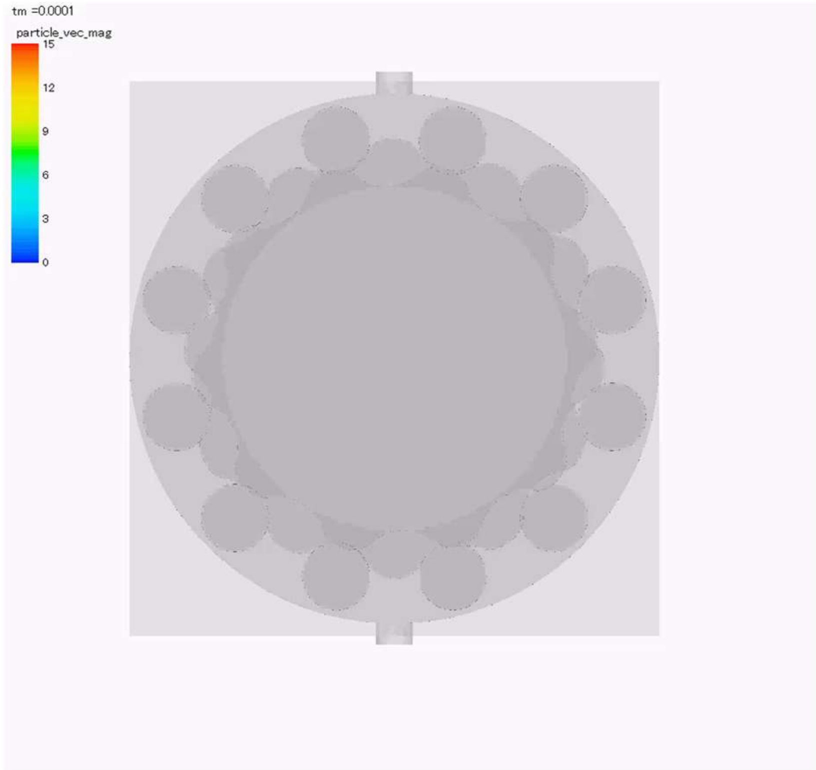


5. Simulation-3

Feed grease to CYCLO GEAR MODEL

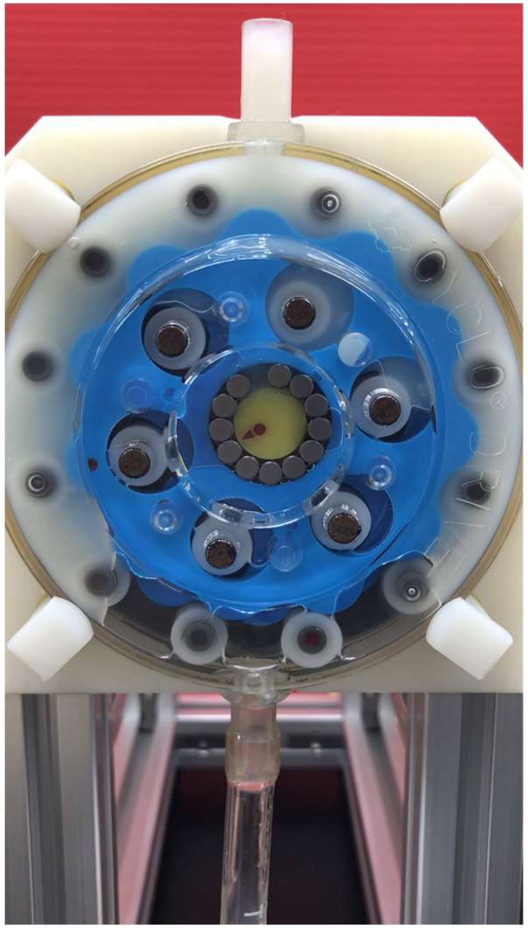
Grease: No. 0, 10 ml/min, No Rotation

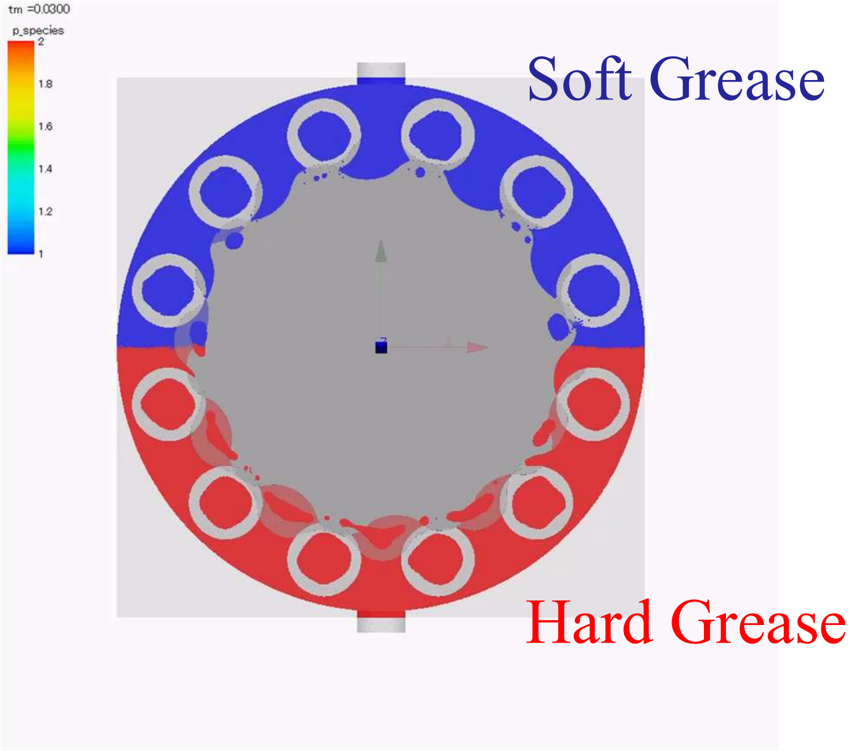




Feed grease to CYCLO GEAR MODEL

Grease: No. 0, Rotation: 60 rpm (Input)





Now Calculating!

6. Conclusion

The flow behavior of grease could be roughly simulated by the DEM-MPS method considering the non-Newtonian properties of the grease.

In future study,

1) Improve the calculation accuracy by optimization of calculation conditions (coupling with mesoscopic simulation etc.).
2) Apply the method to clarify the mechanism of the specific friction and wear properties of INS-UG.

Thank you!!!