IX. Enhancing Gear NVH Through Polymer Infiltration Enabled by Powder Metallurgy –

Matheus Fernandes, M.Sc. (ITA) / Josevaldo Fernandez, Eng. (Eaton)

NVH and lightweight construction are two challenging requirements for transmission systems of electric vehicles. In this context, the intrinsic porosity of powder metallurgy (PM) acts as a damper, which enhances NVH performance. The design flexibility enabled by PM has also been investigated for reducing gear noise. The objective of this work is to examine the NVH behavior of PM gears with polymer infiltration in web-optimized cavities. The damping ratio of four polymer blends was evaluated using simplified specimens through the half-power method in an impact hammer test. Based on these experiments, the blend that offered the highest damping was selected for NVH testing in a gear test rig. A topology-optimized gear was produced, and the polymer was infiltrated into the cavities of its body. Four gear variants were tested, and the benefits of PM material, topology optimization, and polymer infiltration were individually validated. A twelvefold increase in damping was observed for the infiltrated PM gear. A mass reduction of 32% was achieved with the optimized gear while keeping the transmission error at the same level. Additionally, the infiltrated design exhibited a smoother vibration transition during speed changes in dynamic tests. It can be concluded that powder metallurgy and polymer infiltration are promising solutions for addressing the NVH demands of electrified powertrains.

Enhancing Gear NVH Through Polymer Infiltration Enabled by Powder Metallurgy

Matheus Fernandes Vieira, M.Sc. *(ITA)*

Josevaldo Fernandez, Eng. *(Eaton)*

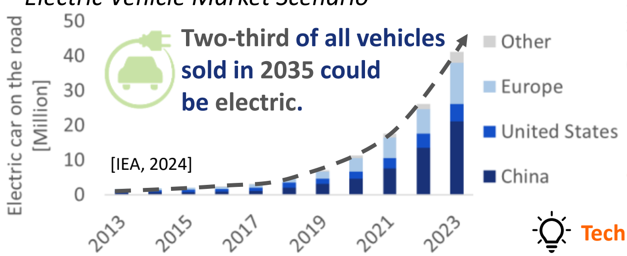
São José dos Campos, August 13th & 14th, 2025

Agenda

Agenda

The Demand for Quieter Gears

Electric Vehicle Market Scenario



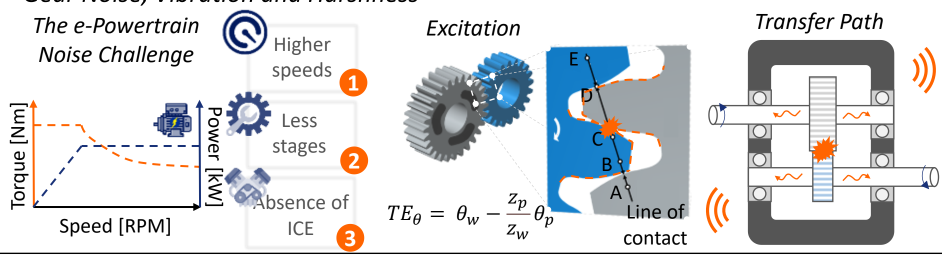
Electric Vehicles Are Noisy in Different Ways, and That's the Engineering Challenge [Car and Driver, 2023]

Obstacles to growth of the electric car market in Brazil [Revista Fapesp, 2023]

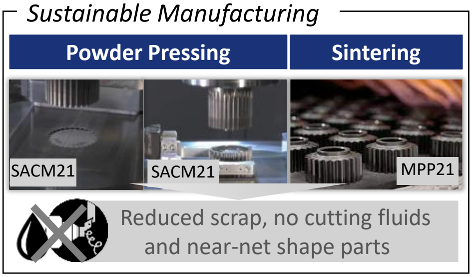
Charging, not range, is becoming a top concern for electric car drivers [The Conversation, 2024]

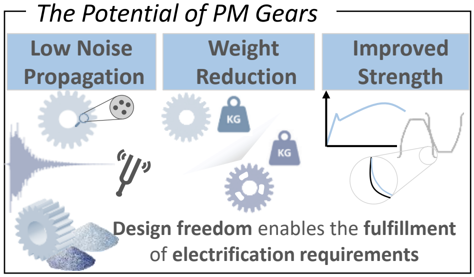
Technological development demand

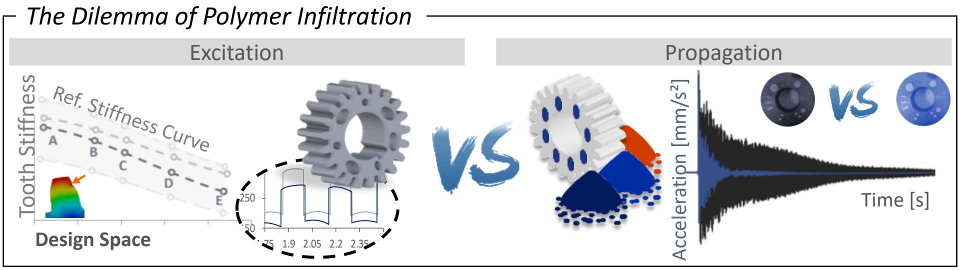
Gear Noise, Vibration and Harshness



Powder Metallurgy and Polymer Infiltration







[SANT24, SANT23]

Objective and Approach

Observation

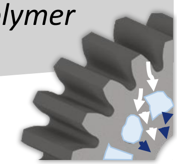
The inherent porosity of PM components enhances structural damping, thereby improving the performance of PM gears.

Hypothesis

Creating optimized holes in the gear web and infiltrating them with polymer could enhance damping and improve NVH performance.

Objective

Potential of NVH enhancement of PM gears with polymer infiltration in web-optimized cavities.



Sub objective #01

Develop the gear topology optimization.

Sub-objective #02

Evaluate the damping properties of polymer-infiltrated gears.

Sub-objective #03

Determine the vibrational characteristics of the optimized and polymer-infiltrated gear.

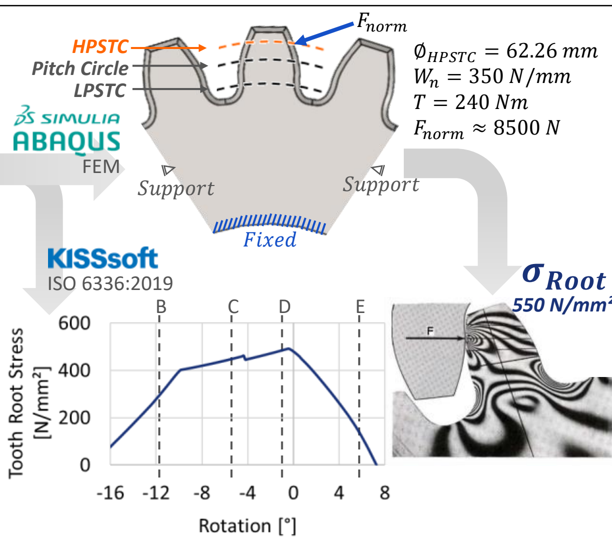
Agenda

Gear Topology Optimization

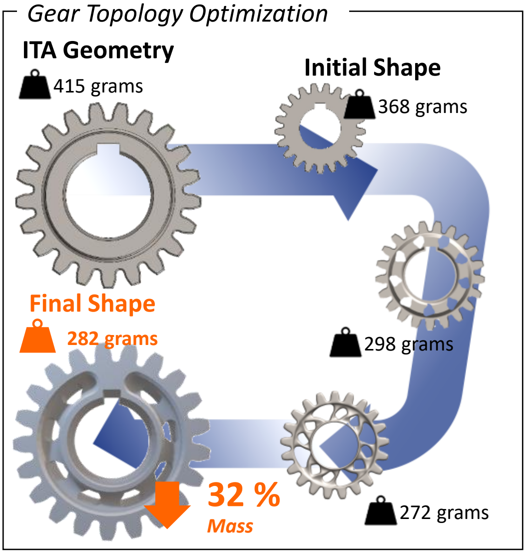
Boundary Conditions

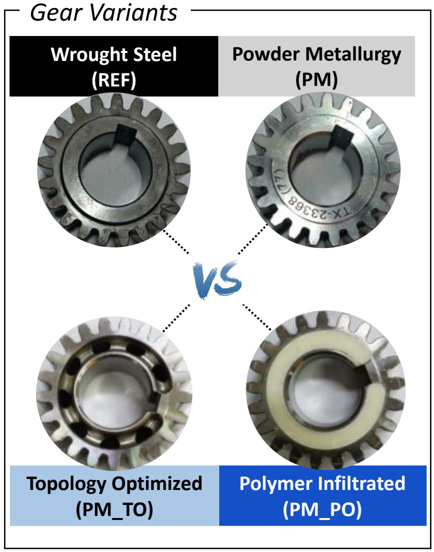
ITA Geometry

- **Center Distance (a):** 71 mm
- **Number of Teeth (z):** 21
- **Normal Module (m):** 2.85 mm
- **Pressure Angle (α):** 17.5°
- **Tip diameter (da):** 65.510 mm
- **Width (b):** 24 mm
- **WS Material:** 16MnCr5
- **PM Material:** Astaloy 85 Mo



Optimized Gear Geometry and Tested Variants



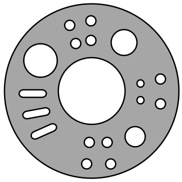


Agenda

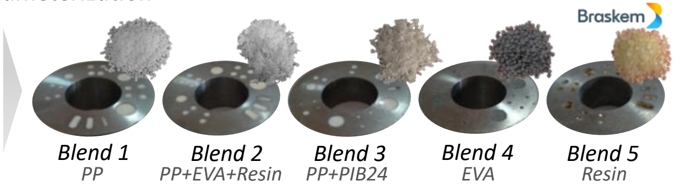
1. Powder Metallurgy Gears for Electrified Powertrains
2. Exploring the Benefits of Powder Metallurgy
3. **Assessing the Benefits of Powder Metallurgy**
4. Summary and Outlooks

Polymer Infiltration and Modal Testing

Polymer Infiltration Parameterization

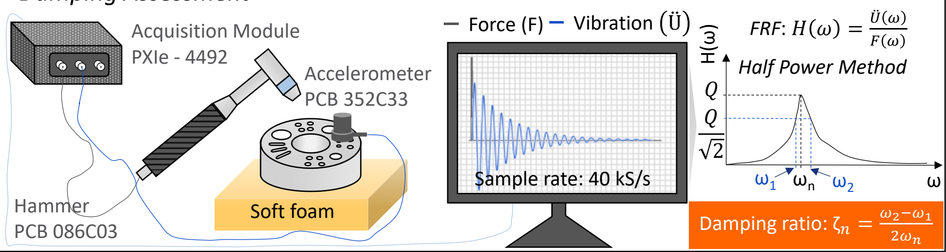


Simplified specimen with PM optimization possibilities



5 polymer blends were developed and infiltrated into the simplified specimen

Damping Assessment

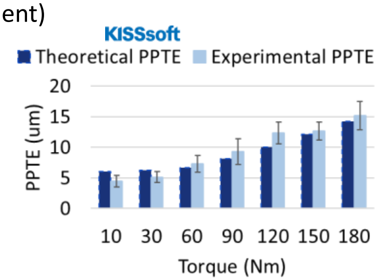


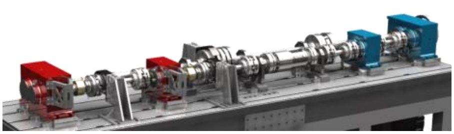
Damping ratio: $\zeta_n = \frac{\omega_2 - \omega_1}{2\omega_n}$

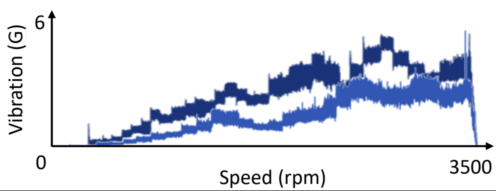
Infiltrated Gear NVH Assessment

NVH Testing Procedure

- **Excitation** (Static Transmission Error measurement)
  - Torque: 0 up to 180 Nm;
  - Speed: 60 rpm (quasi-static condition);
  - Response: PPTE.
- **Structure-Borne Noise**
  - Torque: 0 up to 180 Nm;
  - Speed: 0 up to 3500 rpm;
  - Response: Housing Vibration.

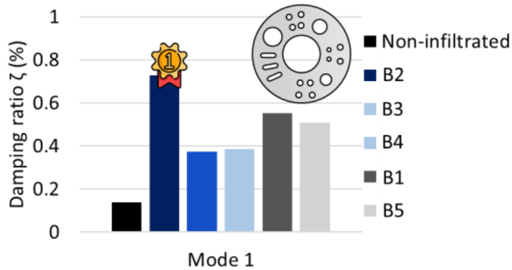


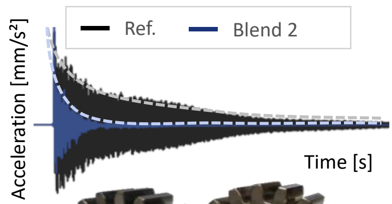




Damping Behavior of Polymer Blends

Polymer Blend Selection Based on Damping Ratio





Increase in Damping

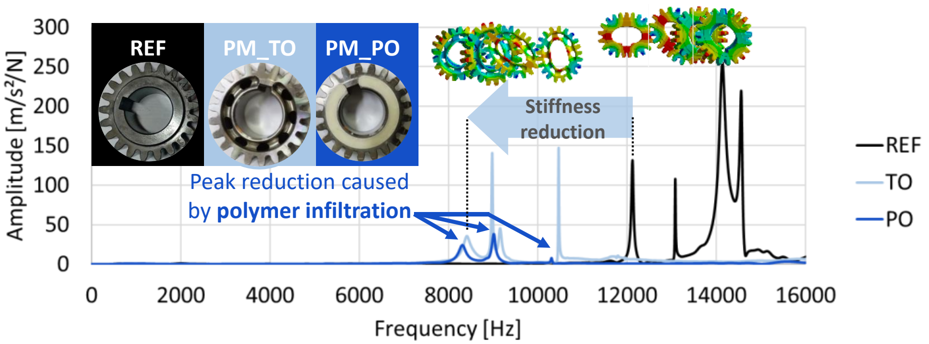
#	B1	B2	B3	B4	B5
Mode 1	300%	427%	171%	179%	268%

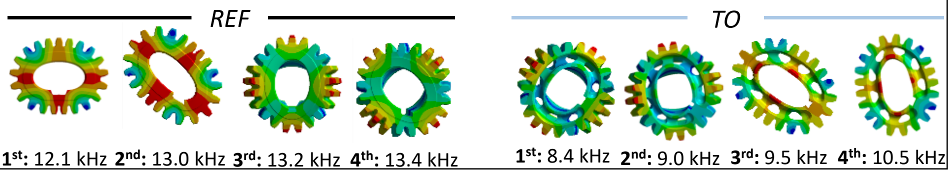
The **"Blend 2"** polymer showed 4 times higher damping compared to the simplified non-infiltrated specimen

The **"Blend 2"** polymer was chosen to infiltrate the gear web and evaluate NVH performance

Gear Variants Modal Analysis

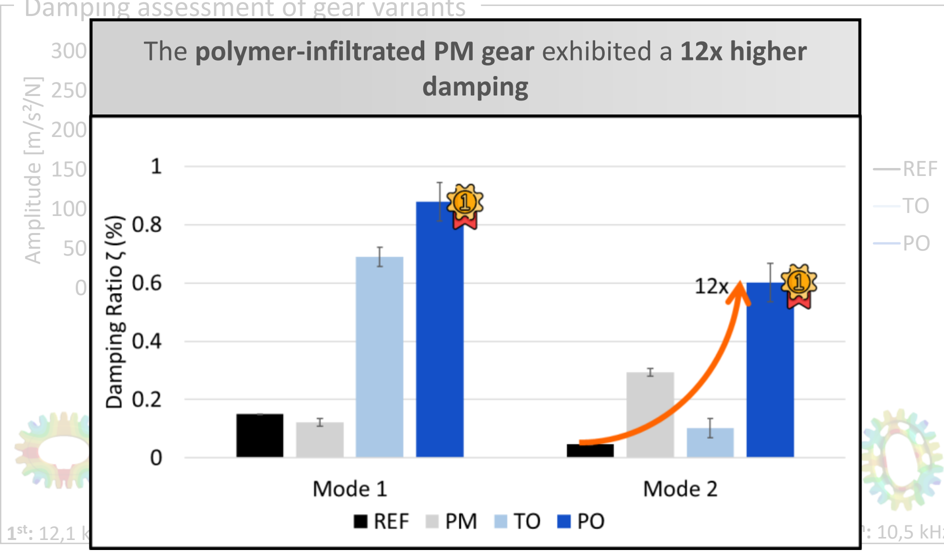
Damping Assessment of Gear Variants





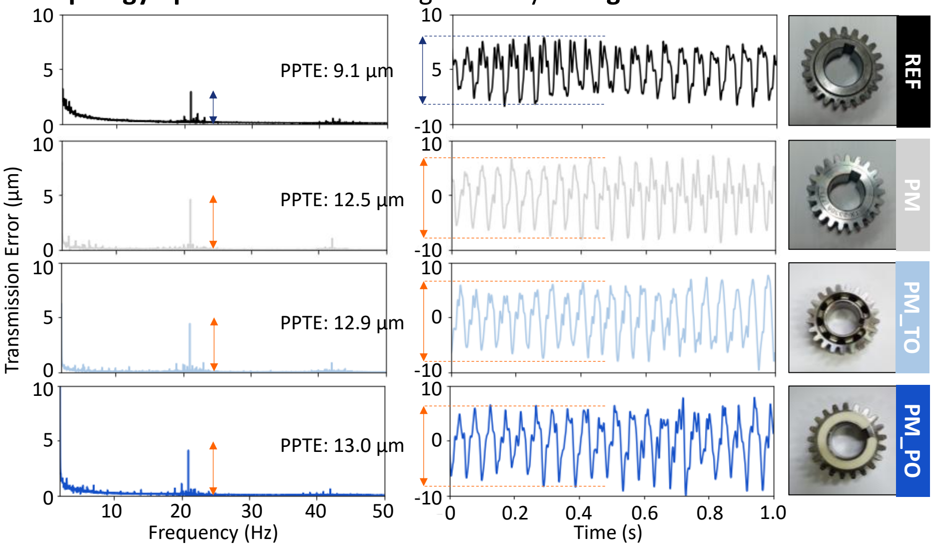
Gear Variants Modal Analysis

The **polymer-infiltrated PM gear** exhibited a **12x higher damping**



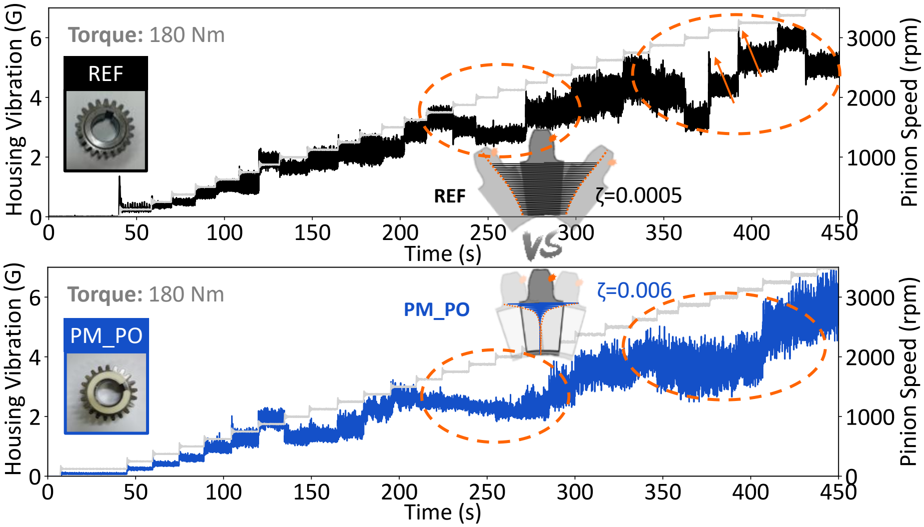
NVH Testing

- **Topology optimization hasn't** significantly **changed** the **static TE**



Gearbox Dynamic Testing

- Gears with **higher damping** exhibited **smoother vibration transients**



Agenda

Summary

- The proposed topology optimization method achieved a **32% reduction in mass** while maintaining the **same level of excitation**;
- The polymer infiltration into the gear web increased structural **damping by a factor of 12**;
- The enhanced structural damping demonstrated strong potential for **attenuating vibration transients**.

Outlooks