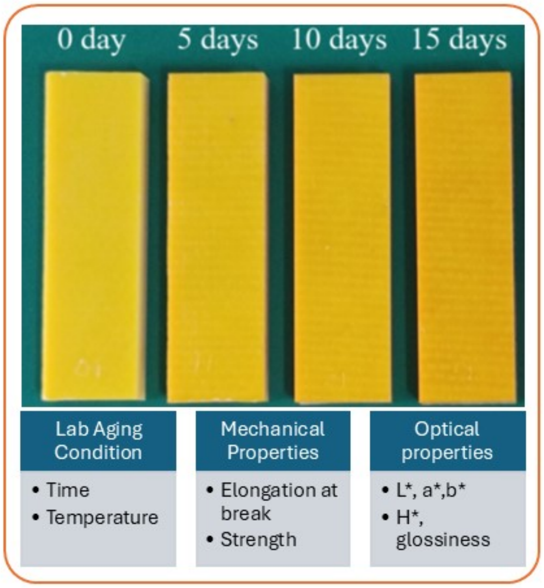
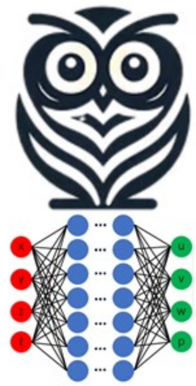
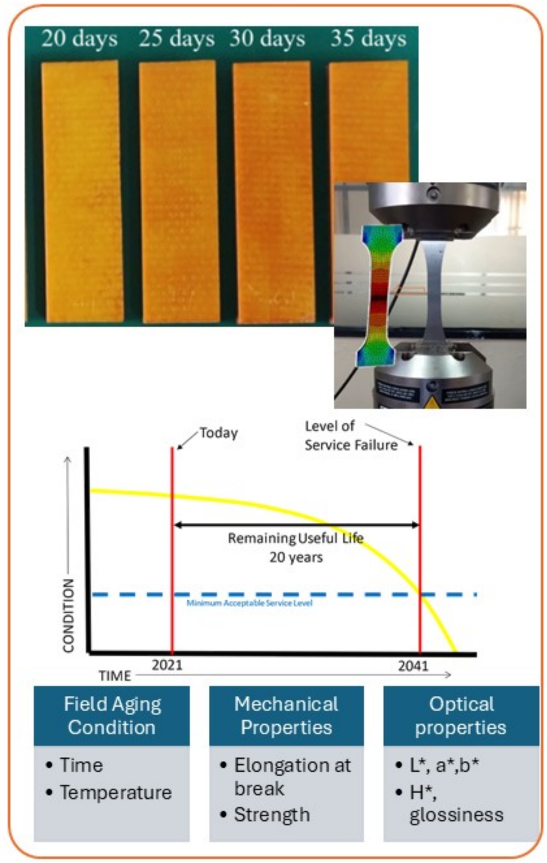
K-Sense: Using RGB Images to predict Aging

Required
Short-term Behavior





Predicted Long-term Behavior



K-SENSE is a Physics-Informed AI Engine that translates standard digital imagery into real-time digital twin for condition monitoring. K-SENSE significantly reduces initial testing required and provides accurate long-term predictions based on images only.

Case Study: Long-term Optical/Mechanical properties of epoxy resin in thermo-oxidative Aging

Predicting the long-term structural integrity of polymer-based assets is a critical challenge across the aerospace, energy, and automotive sectors . Legacy qualification frameworks often rely on simplified empirical "curve fits" that require months of high-density data and frequently fail to predict macroscopic cracking or mechanical embrittlement . For high-performance epoxy resins, traditional models trained on short-term data (2 weeks) typically diverge significantly when forecasting long-term behavior (+3 months), leading to either premature asset replacement or unexpected structural failure.

K-SENSE: Coupling Data and Chemistry

K-SENSE was implemented to monitor an epoxy resin subjected to accelerated thermo-oxidative stress . Unlike standard "black-box" AI solutions that require massive datasets, K-SENSE utilizes a Minimalist Data Strategy grounded in polymer physics:

- **Minimized Lab testing**: Calibrated using only aging tests < **15 days** for model training.
- **Sensor Input:** Utilized standard digital imagery to extract non-destructive CIELAB colorimetric features (L∗,a∗,b∗)
- **Physics Anchor:** Embedded a bi-exponential decay backbone into the model architecture to explicitly separate rapid surface oxidation from slower bulk structural degradation.

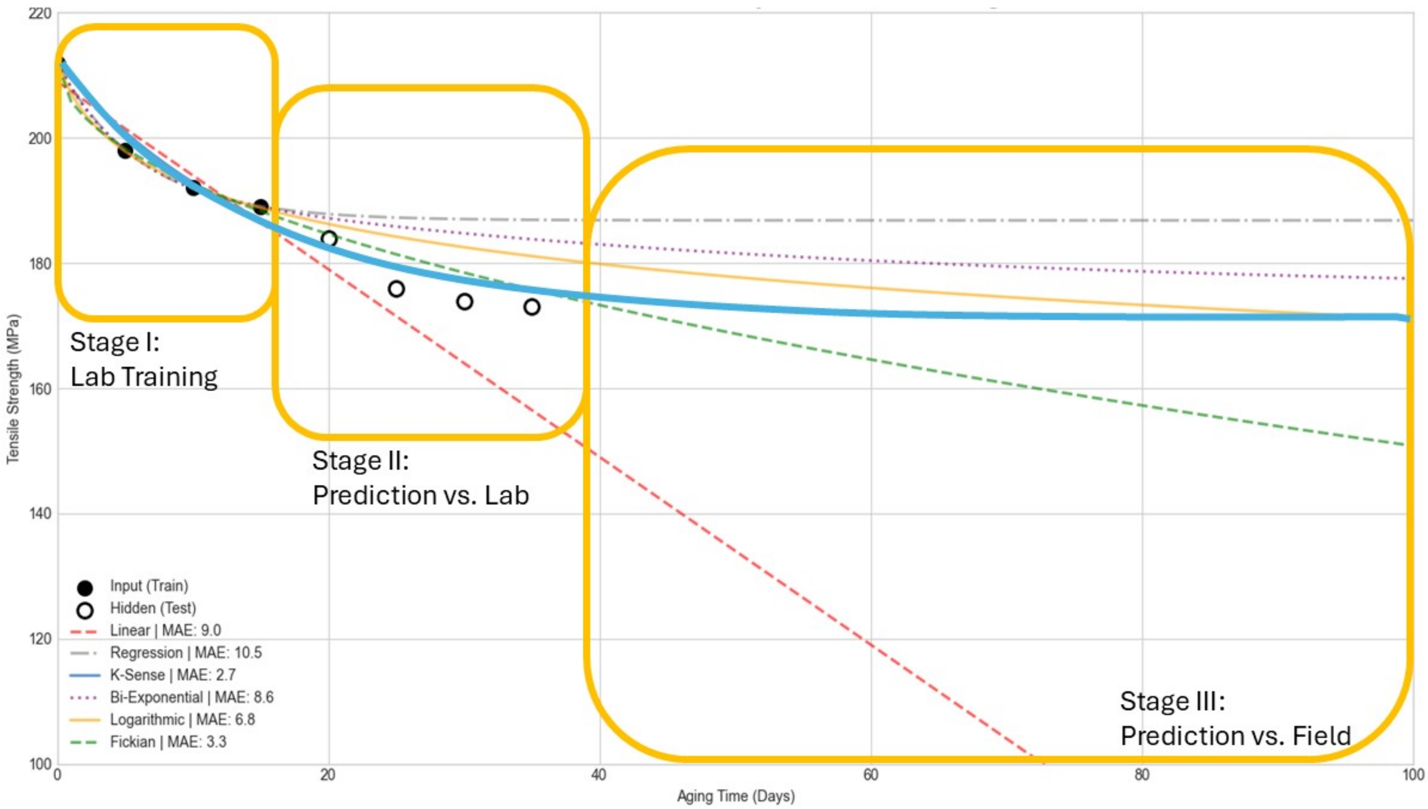
”15-Day Training” Proof of Concept

We implemented a rapid POC using engineering-grade epoxy resin aged at 110 ∘ C

- **Stage I (Data Capture):** Standard CIELAB features (L∗, a∗, b∗, h) were extracted non-destructively.
- **Stage II (Residual Physics):** The model predictions was validated against current standard models.
- Stage III (Field Relevance): +3 month predictions of different models were plotted were K-sense is clearly surpassing others as the most accurate and most interpretable model.

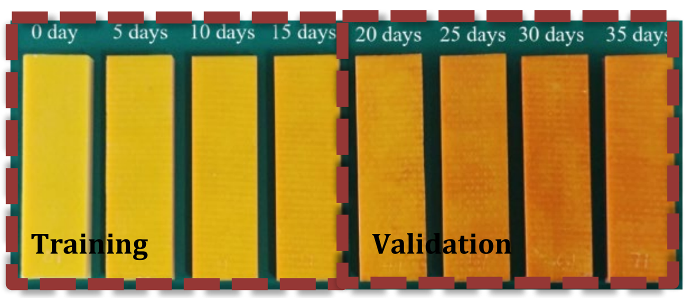
Key Outcomes: Advanced Predictive Analytics

The K-SENSE proof-of-concept achieved three critical industrial breakthroughs:



- **Concurrent Multimodal Prediction:** K-Sense can predict long-term behaviour of the material in three aspects:
  - Mechanical Properties (EAB, strength)
  - Optical Properties (future discoloration, yellowing, Glossiness)
  - Damage Accumulation to calculate other parameters, e.g. carbonyl index
- **Concurrent Multimodal Prediction:** K-Sense can predict long-term behaviour of the material in three aspects:
- **Reliable Remaining Useful Life (RUL)**: By identifying the transition from the induction period to significant embrittlement, the model successfully forecasted the Time-to-Failure and RUL based solely on early-stage induction signatures.
- **Long-term Accuracy:** In predicting long-term behaviour (+1 year), standard models (Linear, Bi-Exponential, and Fickian) yield extreme erros —including near zero or negative strength predictions—K-SENSE remained asymptotically stable and physically consistent across a 1000-day extrapolation horizon.

Extrapolation Trap: For resins, traditional models calibrated on short-term data (2 weeks) diverge significantly (+3 months) because they ignore underlying chemical vs. mechanical decay rates



Reduced Risk & Accelerated Timelines

By substituting "Big Data" with "Physics-Informed Intelligence," K-SENSE eliminates the need for long-duration laboratory aging tests. This allows industrial partners to:

- **Reduce Testing Time:** Predict months of performance from just 15 days of observation.
- **Minimize Data Requirements:** Achieve superior accuracy with 60% less training data than legacy empirical frameworks.
- **Scale Across Material Families:** Adapts rapidly to new formulations by refining Mechanistic Parameters rather than observable data points .

Metric	Industry Standard (Empirical)	K-SENSE Target
Data Requirement	3-6 months of high-density data	**15 Days (Minimalist)**
Prediction Stability	Diverges after training window	**Asymptotic Stability**
Prediction Error	High MAE in long-term	**MAE: 2.7 MPa**
Failure Prediction	Reactive (Post-failure)	**Proactive (RUL Estimation)**