Conductive Thermoplastic Polymer Composites for Road Infrastructure

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Motivation: Winter Maintenance Has Hidden Costs

De-icing salts

Mechanical clearing

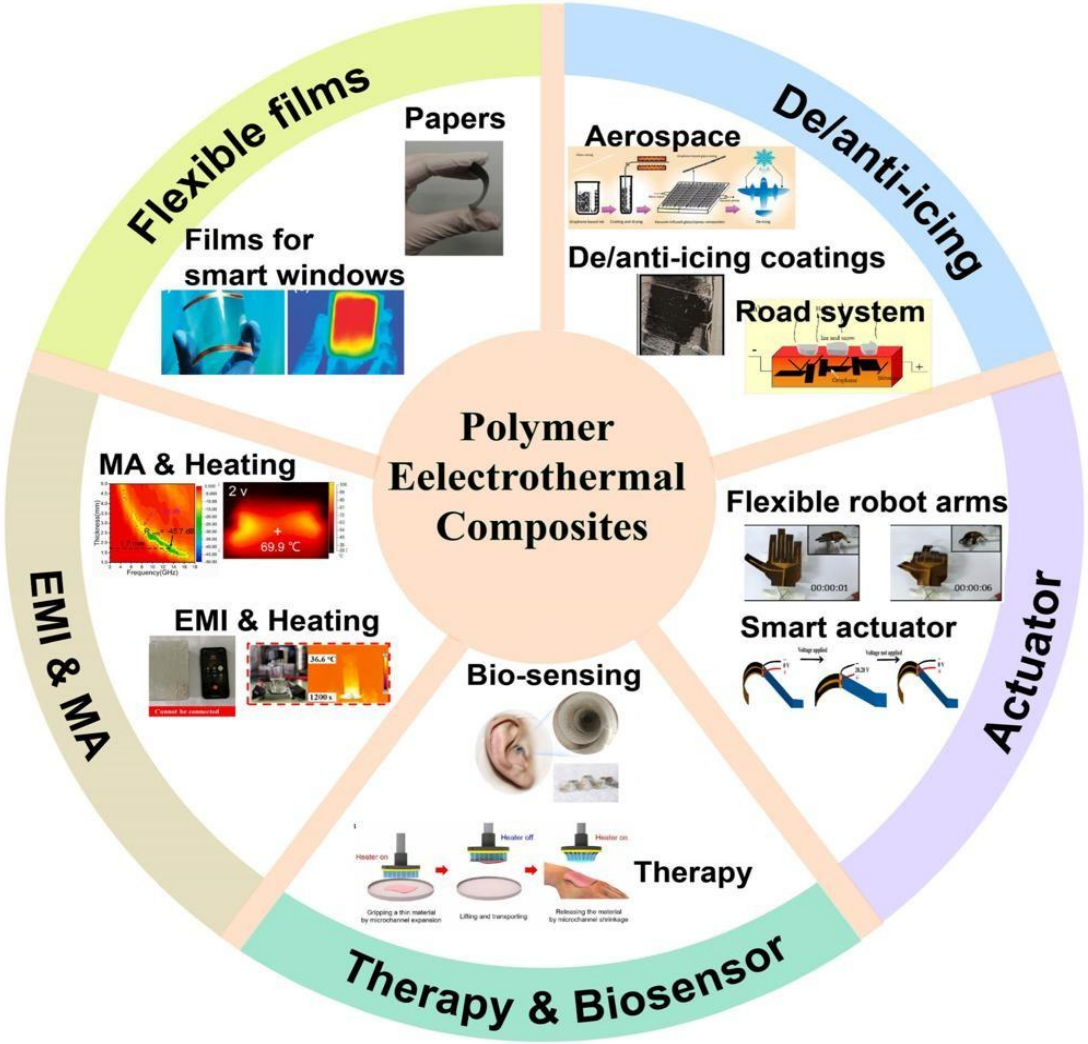
Why alternatives matter

- Salts accelerate corrosion of infrastructure and vehicles
- Chemical runoff harms the environment
- Freeze–thaw + chemicals increase pavement degradation and maintenance cost

Proposed Solution: Conductive Thermoplastic Composites

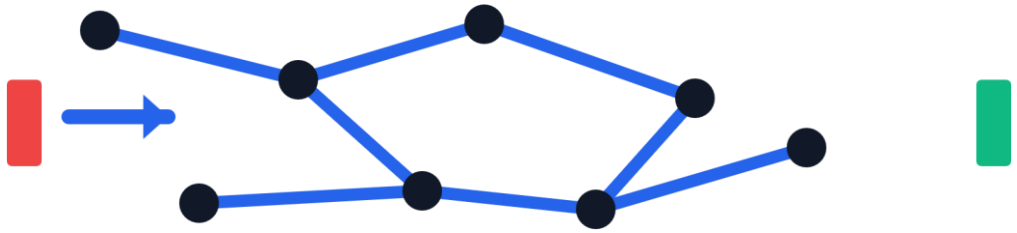
A single functional layer can:

- Generate heat (Joule heating) to prevent icing / melt snow
- Sense traffic loads via piezoresistive response
- Enable rapid repair/rewelding thanks to thermoplastic matrix
- Support retrofit installation on critical segments (bridges, ramps)



How It Works: Percolation + Joule Heating + Sensing

1) Conductive network (percolation)

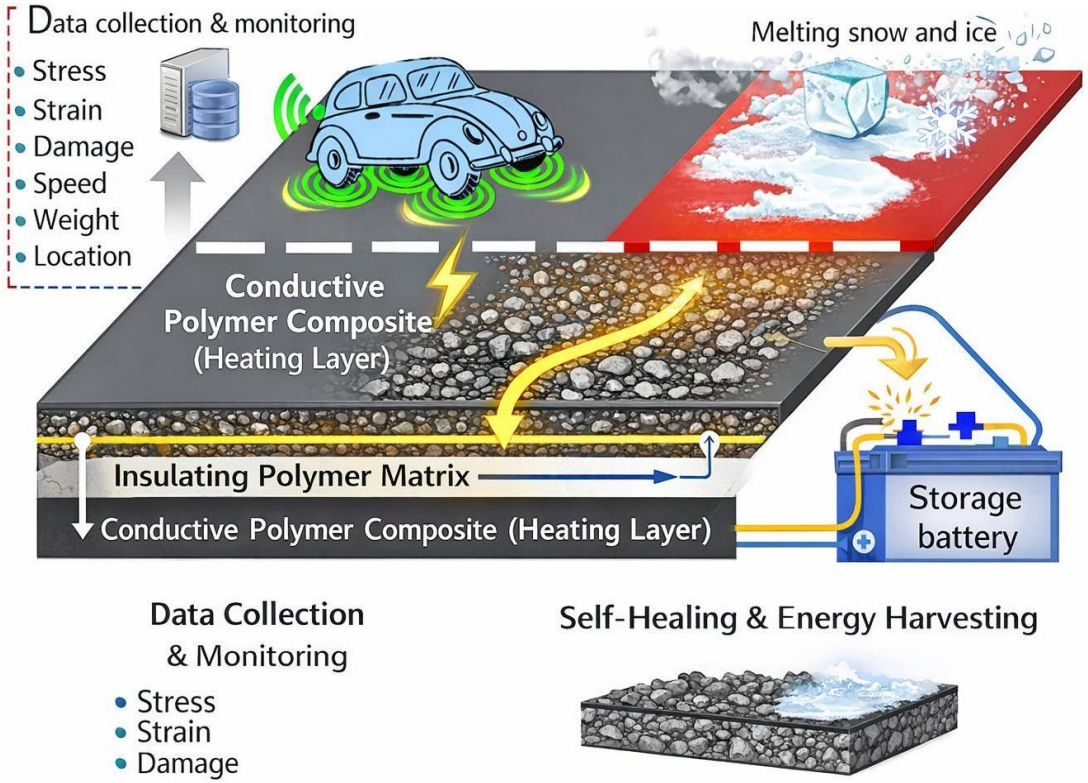


2) Joule heating ($Q = I^2 * R * t$)

Heat is generated in the conductive pathway, weakening ice adhesion and melting snow.

3) Piezoresistive sensing

Under load, the network changes → resistance changes (strain/weight sensing).



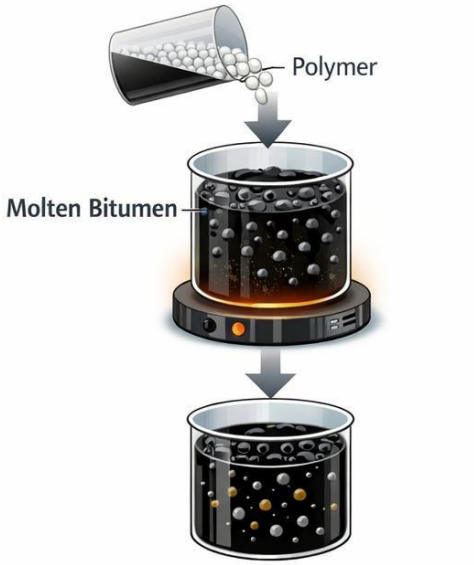
Smart road surface scheme

From Lab Material to Pavement: Processing & Compatibility

Thermoplastics + bitumen: two routes

Wet Modification

Polymer added directly to bitumen



Polymer Modified Bitumen

Wet modification

Polymer blended into the binder (typical dosages depend on binder & polymer)

Dry Modification

Polymer added to asphalt mix in solid form

Polymer Modified Asphalt

Dry modification

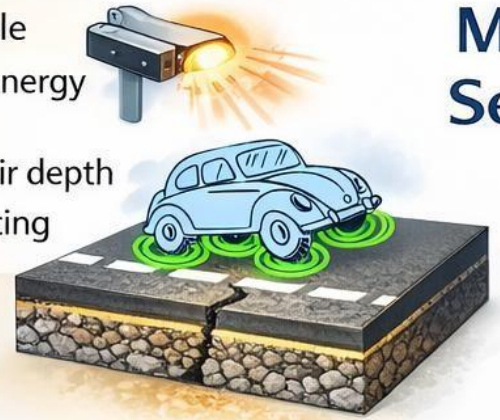
Polymer added as solid to asphalt mix; requires good dispersion & mixing control

Methods of self-healing of road surfaces

Methods of Self-Healing Asphalt

Thermal Healing

- ✓ Easy principle
- ✗ Significant energy demand
- ✗ Limited repair depth
- ✗ Uneven heating

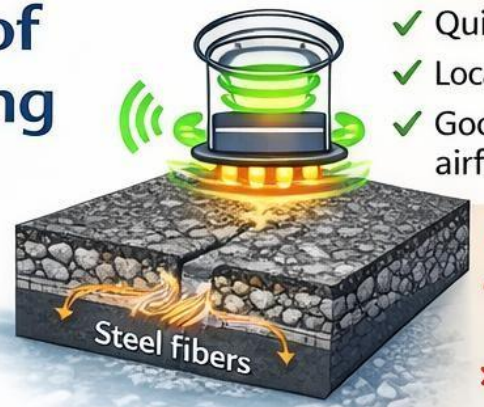


Benefits:

- ✓ Easy principle

Induction Heating

- ✓ Quick repair
- ✓ Localized smart control
- ✓ Good for bridges and airfields



Challenges:

- Requires special equipment
- ✗ Weight and cost of steel particles

Microwave / RF Heating

- ✓ Fast, deep heating
- ✓ Works for asphalt and composites

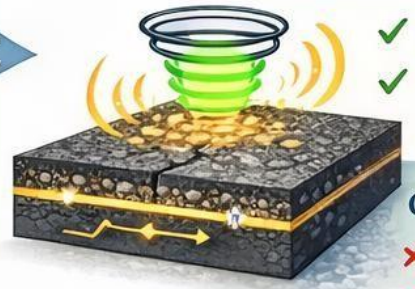
Challenges:

- Needs radiation-safe equipment

✓ **Microwave / RF Heating**

- ✓ Fast, deep heating
- ✓ Works for asphalt and composites

Conductive Composites



- ✓ Precise heating control
- ✓ Multiple functions (eg, sensing, anti-icing) in one layer

Challenges:

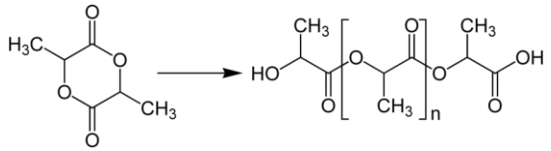
- ✗ Avoid filler degradation
- ✗ Energy / salt / moisture exposure

✓ Teple **tn-sed heating** • Multiple **functions** (e.g, sensing, anti-icing) in one layer

- ✗ Avoid filler degradation
- ✗ Energy / salt / moisture exposure

Materials: PLA Matrix + Carbon Black Filler

Why PLA (polylactide)?

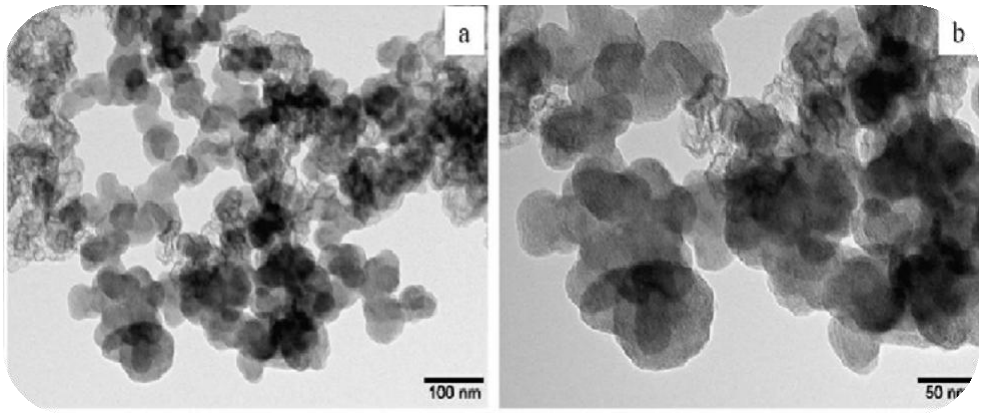


- Thermoplastic: easy processing, welding and repair by reheating
- High stiffness/strength among biopolymers (reported E ≈ 3.5 GPa, σt ≈ 50 MPa)
- Renewable feedstocks; biodegradable mainly under industrial composting conditions

Why carbon black (Printex XE-2B)?

- Forms percolation network at moderate loadings
- Cost-effective vs CNTs/graphene/silver
- Potential to use recovered carbon black from waste streams (e.g., tires)

Pellet feedstock (illustrative)

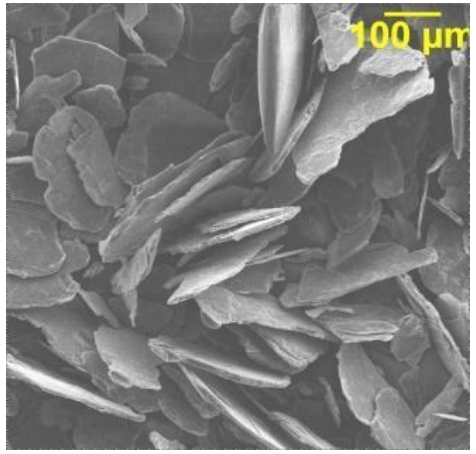


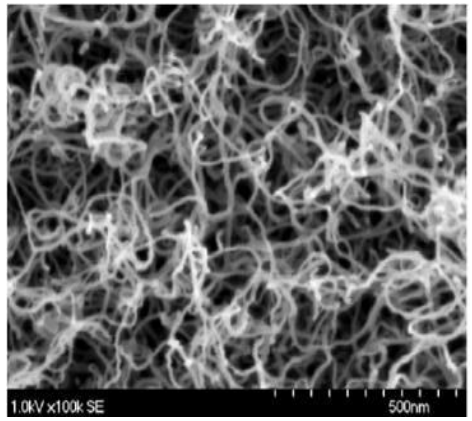
Carbon black microstructure (TEM)

Why Carbon Black: Cost Advantage vs Other Conductive Fillers

Representative prices

Filler	Indicative price / kg
Carbon black (PRINTEX® XE 2B)	≈ $2.6
Battery carbon black (Super-P Li)	$25–35
Industrial CNTs	$199–450
MWCNTs (lab packaging)	$600–25,000
Graphene nanoplatelets	$500–25,000
Silver powder	€1,520





1) https://plastic-price.com/product/orion-engineered-carbons-printex-xe-2b-conductive-carbon-black.html
2) https://www.gelon-lib.com/sale-33889170-conductive-carbon-black-super-p-li-for-li-ion-battery-cathode-raw-materials.html
3) https://www.ctimaterials.com/product-category/industrial-carbon-nanotubes-products/
4) https://www.cheaptubes.com/product-category/multi-walled-carbon-nanotubes/
5) https://www.ctimaterials.com/product-category/graphene-nanoplatelets/
6) https://www.sigmaaldrich.com/NL/en/product/aldrich/gf07503825

Technological and performance additives: plasticizers

Propylene carbonate (PC)

Ethylene vinyl acetate copolymer (EVA)

Goal:

Improve conductivity while keeping mechanical performance suitable for a functional pavement layer.

Formulations (all with 10 wt.% carbon black)

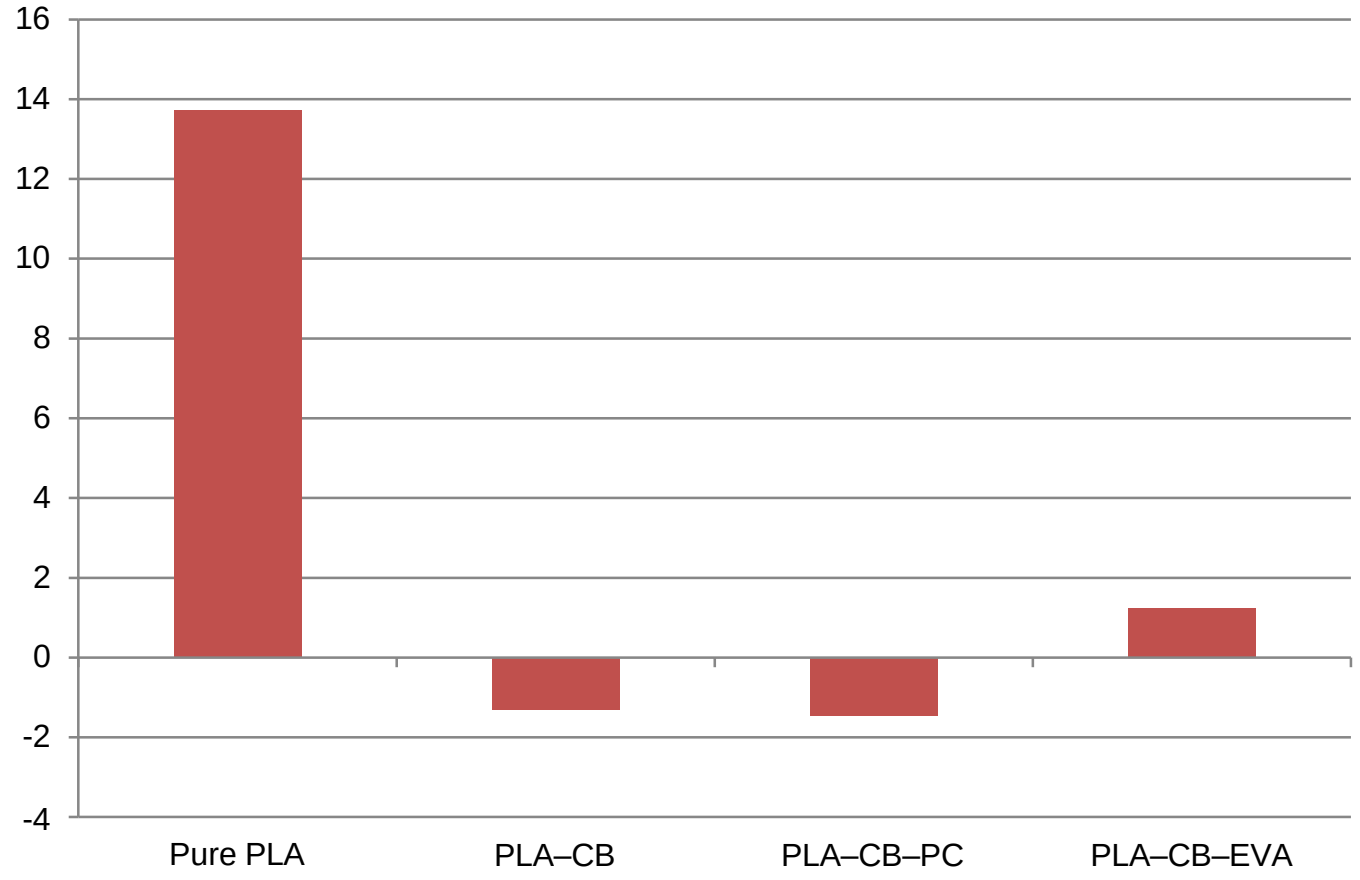
- Pure PLA (baseline)
- PLA–CB (10 wt.% CB)
- PLA–CB–PC (20% propylene carbonate plasticizer)
- PLA–CB–EVA (20% ethylene–vinyl acetate copolymer)

Measurements

- Electrical: 4-point probe on a Jandel RM3000 (Jandel Engineering, UK) (ρ, Ω·m)
- Mechanical: tensile tests a universal testing machine GP UG 5 DLC-0,5 DVT (DEVOTRANS, Turkey) per ISO 527-1 / ISO 527-3 (50 mm/min)

Electrical Performance: Percolation Achieved at 10 wt.% CB

Specific volume resistivity (log_{10} scale, Ω·m)



ρ (Ω·m): PLA 5.2×10^{13} • PLA–CB 0.049 • +PC 0.035 • +EVA 17.88

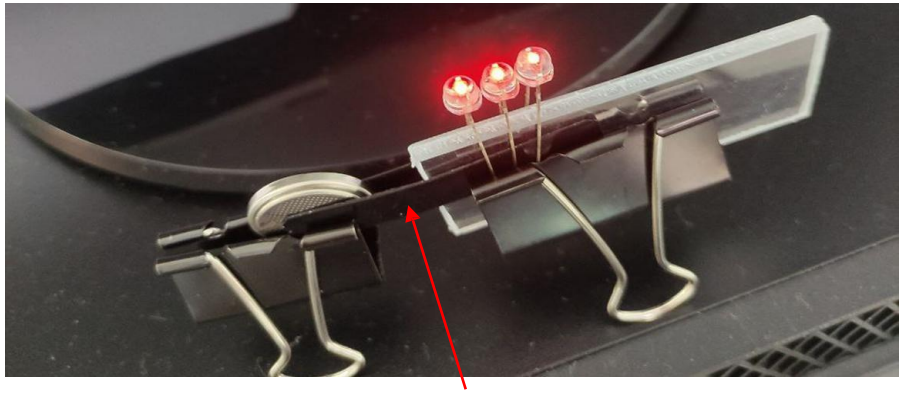
Key observations

- Adding 10 wt.% CB drops resistivity by ~15 orders of magnitude vs pure PLAPropylene carbonate (PC) slightly improves conductivity furtherEVA plasticizer dramatically increases resistivity

Electrical Performance: Percolation Achieved at 10 wt.% CB

Specific volume resistivity (log_{10} scale, Ω·m)

Composition title	PLA, wt. %	CB, wt. %	ρ, Ω×m
Pure PLA	100	0	$5{,}20 \times 10^{13}$
PLA-CB	90	10	0,049
PLA-CB-PC (20% of plasticizer)	70	10	0,035
PLA-CB-EVA (20% of plasticizer)	70	10	17,880



The resulting PLA-CB-PC composite

Key observations

- Adding 10 wt.% CB drops resistivity by ~15 orders of magnitude vs pure PLAPropylene carbonate (PC) slightly improves conductivity furtherEVA plasticizer dramatically increases resistivity

Mechanical Performance: Trade-offs with Plasticizers

Tensile properties (ISO 527)

Composition title	Modulus, MPa	Strength, MPa	Elongation, %
Pure PLA	2310,05	88,95	3,97
PLA-CB	2900,30	30,05	2,81
PLA-CB-PC (20% of plasticizer)	289,22	10,71	58,33
PLA-CB-EVA (20% of plasticizer)	2310,50	17,47	3,36

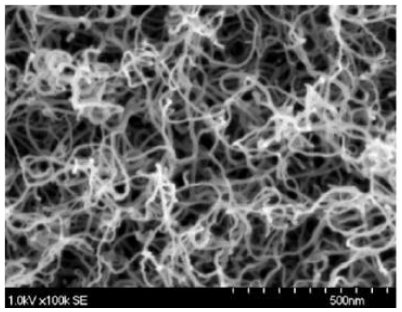
Interpretation

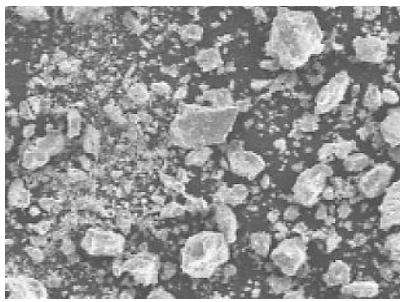
- CB increases stiffness but reduces strength vs pure PLAPC plasticizer yields very high ductility (≈58% elongation) but greatly reduces modulus/strengthEVA keeps modulus closer to PLA but conductivity suffers (see Slide 10 & 11)

Basic principles of modifying the composition of a bituminous binder for microwave-induced

Bitumen

nanodisperse modifiers

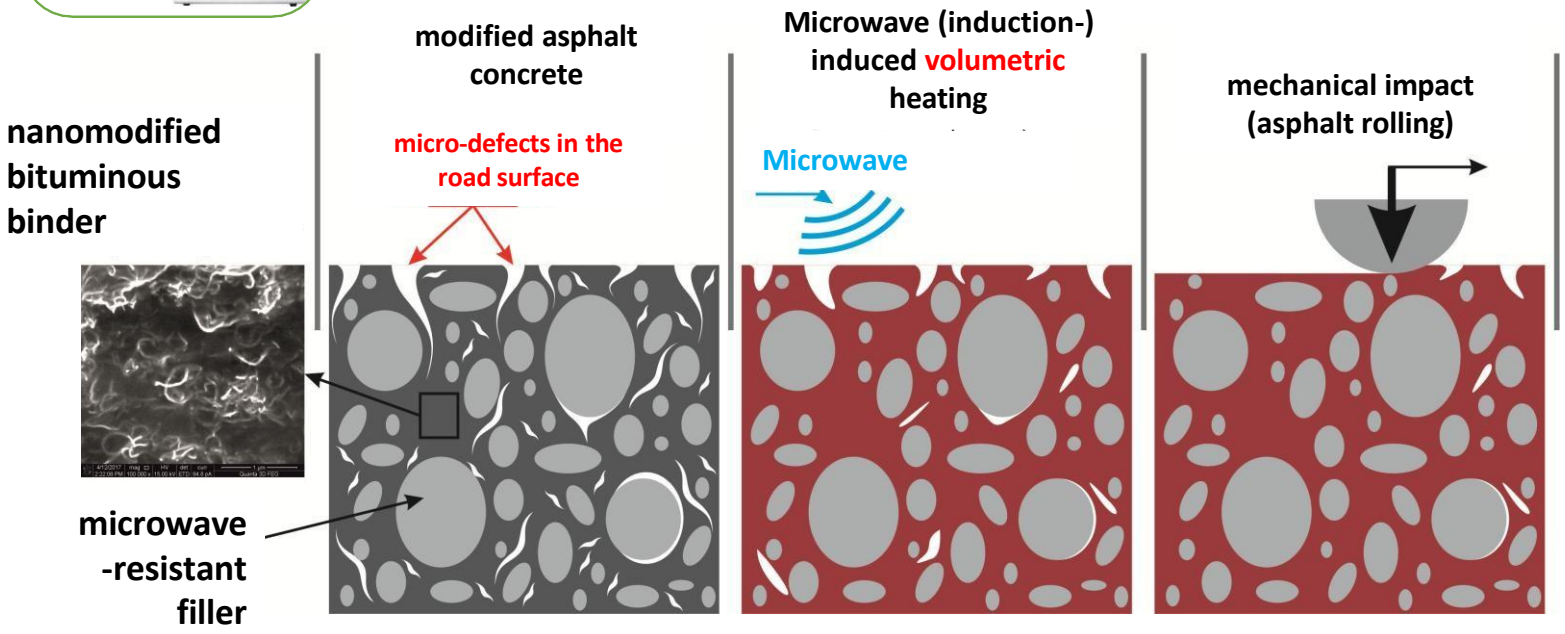




Production of asphalt concrete based on modified bitumen, production of road surface

High-energy processing (ultrasonic, microwave)

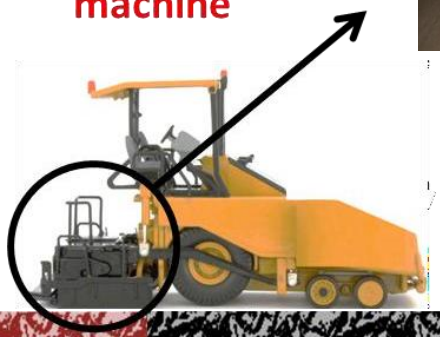
Self-healing of defects and restoration of the road surface without replacing the wear layer

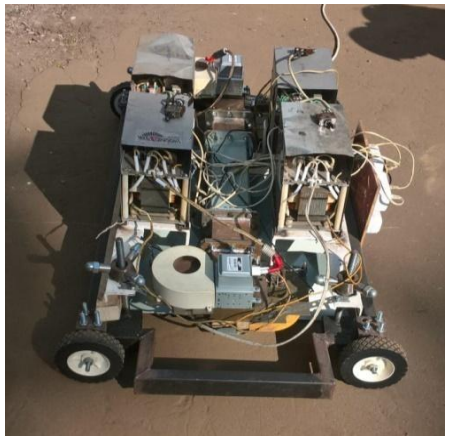


The principle of microwave-induced self-healing and restoration of the road surface wear layer

Conventional wheel roller

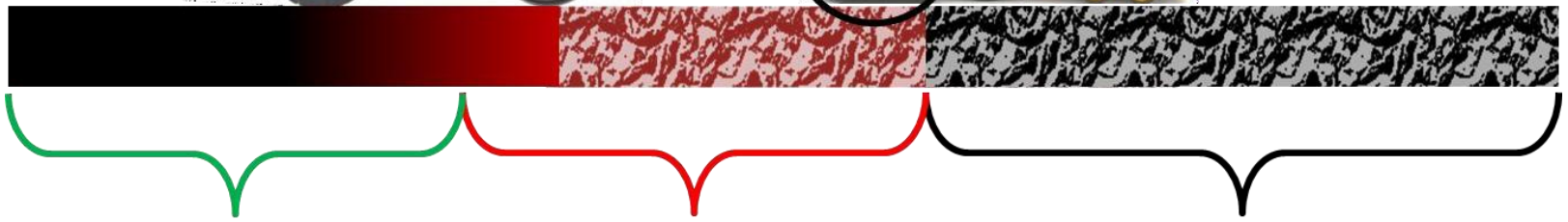
Microwave heater machine





Experimental prototype

An experimental prototype



recovered asphalt

Microwave heated asphalt (partial healing of microcracks)

Asphalt with microcracks

Key Takeaways

- PLA + 10 wt.% carbon black achieves electrical percolation ($\rho \sim 10^{-2}$ Ω·m range)
- Propylene carbonate improves conductivity and ductility, but strongly softens the material
- EVA plasticizer degrades conductivity (not preferred for electro-heating)
- Concept enables multi-function pavement: anti-icing + sensing, with thermoplastic repairability

Next steps: durability under traffic & freeze–thaw, moisture/UV protection, and power optimization.

Thank you!