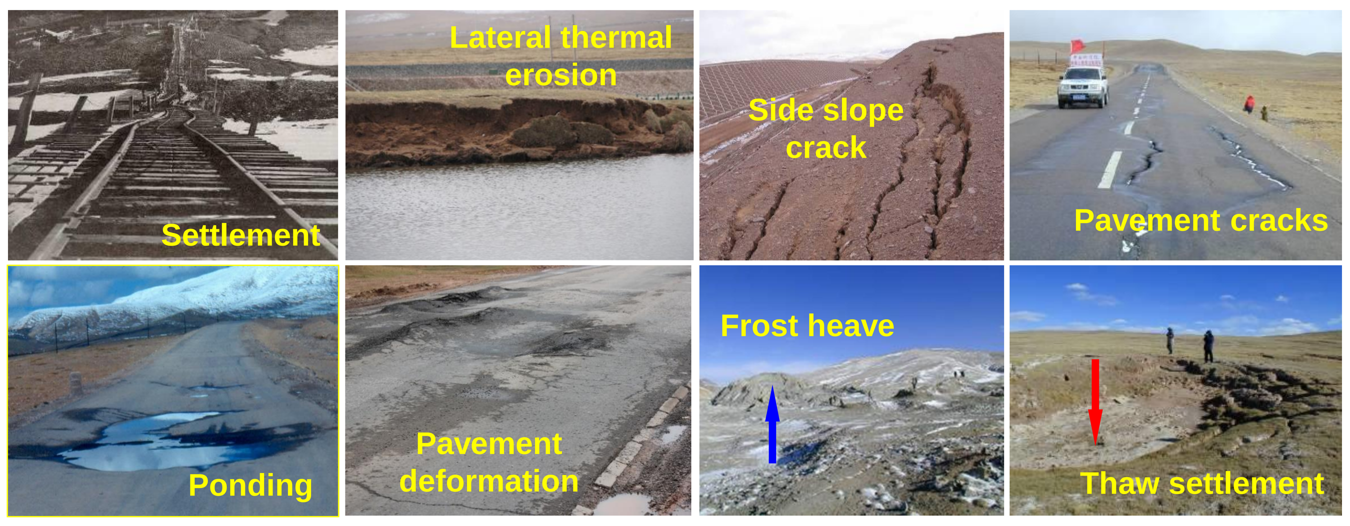
International Association of Chinese Infrastructure Professionals

Impacts of Lightweight Aggregates ACEs on Pavement Performance in Alaskan Permafrost Regions

Student: Hanli Wu, Missouri University of Science and Technology, hwvfn@mst.edu
Research Associate: Dr. Yizhuang David Wang, Missouri University of Science and Technology
Co-advisors: Drs. Jenny Liu and Xiong Zhang, Missouri University of Science and Technology

INTRODUCTION

- Much of the interior of Alaska is underlain by thaw-unstable permafrost or frozen ground.
- Engineering projects often cause a disturbance of the pre-existing thermal balance and subsequent permafrost thawing.
- The air convection embankment (ACE) is an excellent technique to protect the permafrost from thawing.
- However, the desired material (i.e., suitable crushed rocks) needed for ACE are not readily available in Alaska. The shipping cost of crushed rocks from remote area is often prohibitively high.
- Lightweight aggregates as cost-effective and high-performance materials shows great potential as alternative for ACE design.
- Previous study indicated that the cost benefit and thermal performance of lightweight aggregates was significantly better than that of the conventional sand/gravel embankment and the crushed-rock ones.
- However, the impacts of lightweight aggregates on overall asphalt pavement remains unclear.



Freeze-thaw induced damages.

OBJECTIVES

- To evaluate the thermal performance of the pavement structures with the select interlayers.
- To evaluate the pavement responses and fatigue failure of the Hot Mix Asphalt (HMA) layer and functional failure of subgrade soil.
- To provide recommendations regarding interlayer materials to reduce the pavement damage caused by thaw settlement and climatic extremes.

METHODOLOGY

Materials

Crushed rocks

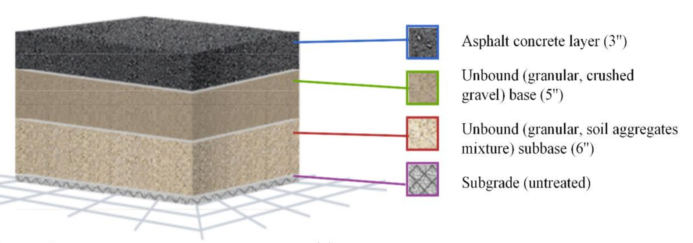
Cellular concrete

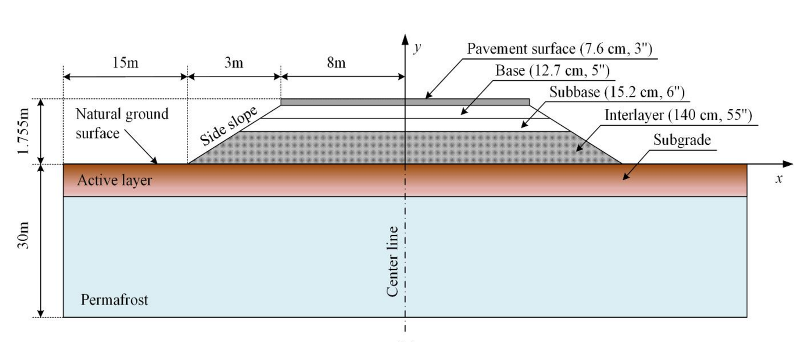
Foam glass aggregate

Numerical Simulation

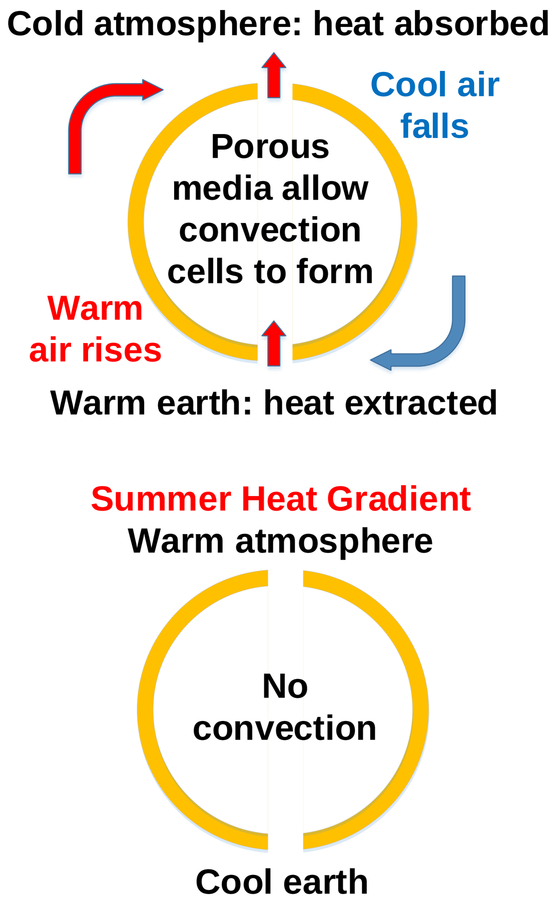
- Computational models
  - ✓ Case 1: typical Alaskan pavement (Control, AK)
  - ✓ Case 2: silty sand gravel embankment (SG)
  - ✓ Case 3: crushed-rock ACE (CR)
  - ✓ Case 4: cellular concrete ACE (CC)
  - ✓ Case 5: foam glass aggregate ACE (FGA)
  - ✓ Case 6: lightweight clay aggregate ACE (LECA)
- Pavement thermal analysis
  - ✓ TEMPS analysis
  - ✓ ANSYS Fluent analysis
- Pavement performance analysis
  - ✓ FlexPAVE™ analysis
  - ✓ AKFPD analysis

Lightweight expanded clay aggregate





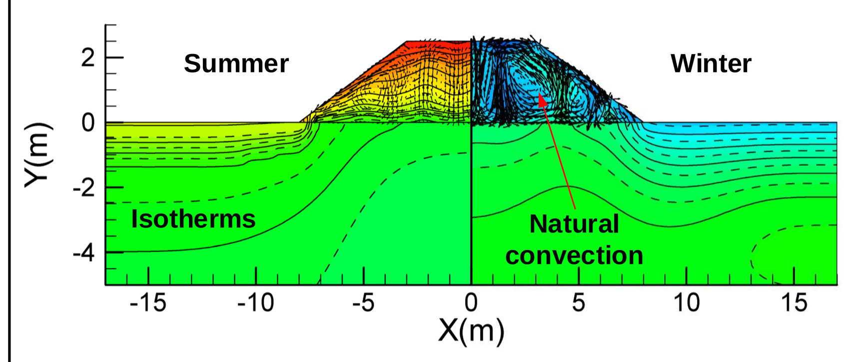
Geometry of the pavement infrastructure. (a) typical Alaskan pavement schematic. (b) embankment schematic.



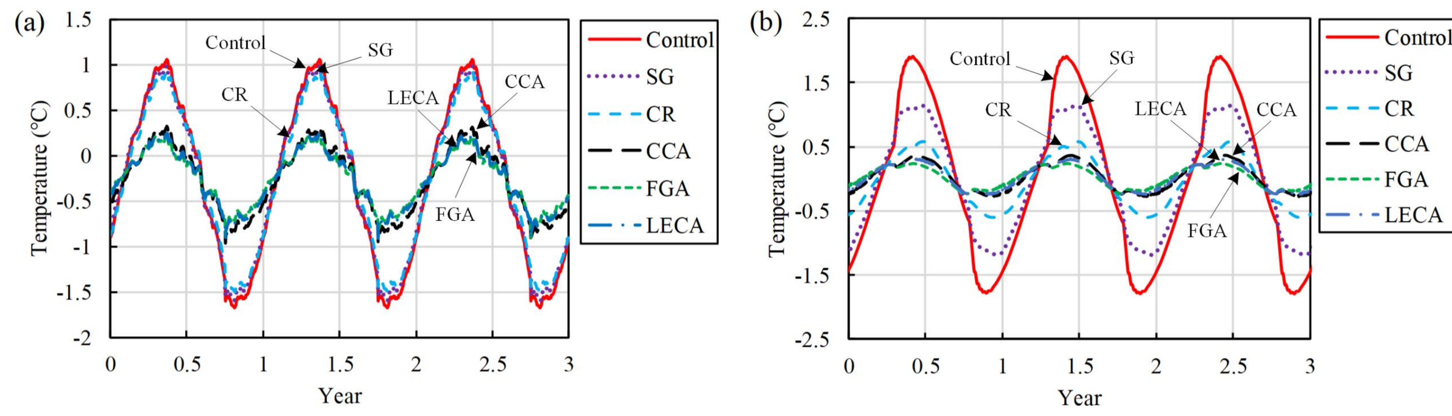
Cooling mechanism of ACE.

PAVEMENT THERMAL RESULTS AND ANALYSES

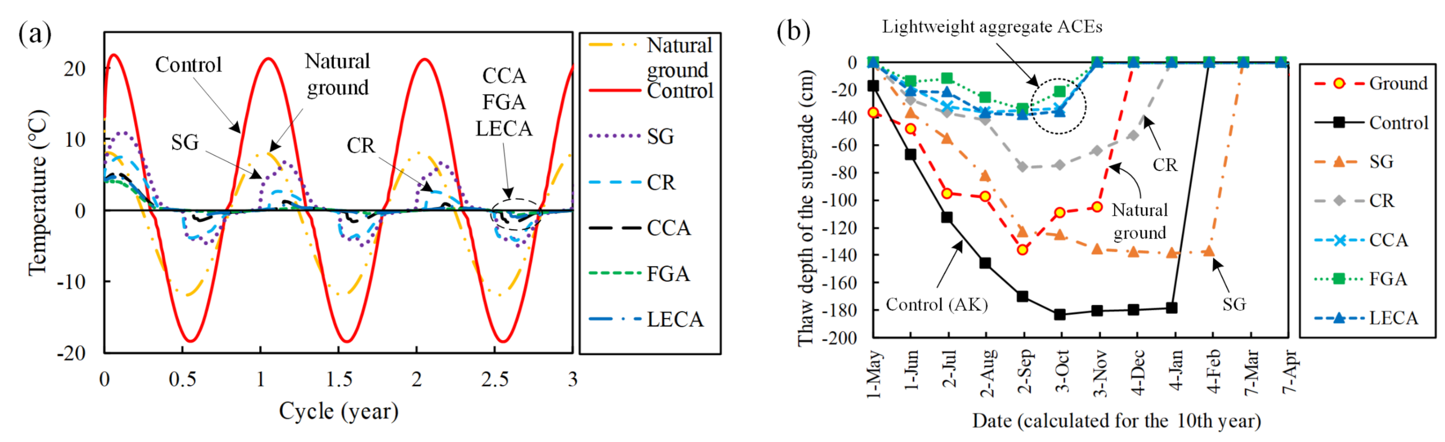
- Heat transfer of ACE includes two patterns: heat conduction and heat convection.
- TEMPS cannot fully consider heat and air convection in ACEs. This issue was addressed by ANSYS Fluent.
- Lightweight aggregates could effectively reduce temperature gradients of HMA layers.
- The lightweight aggregates strategy can significantly reduce the thaw depth of the subgrade.



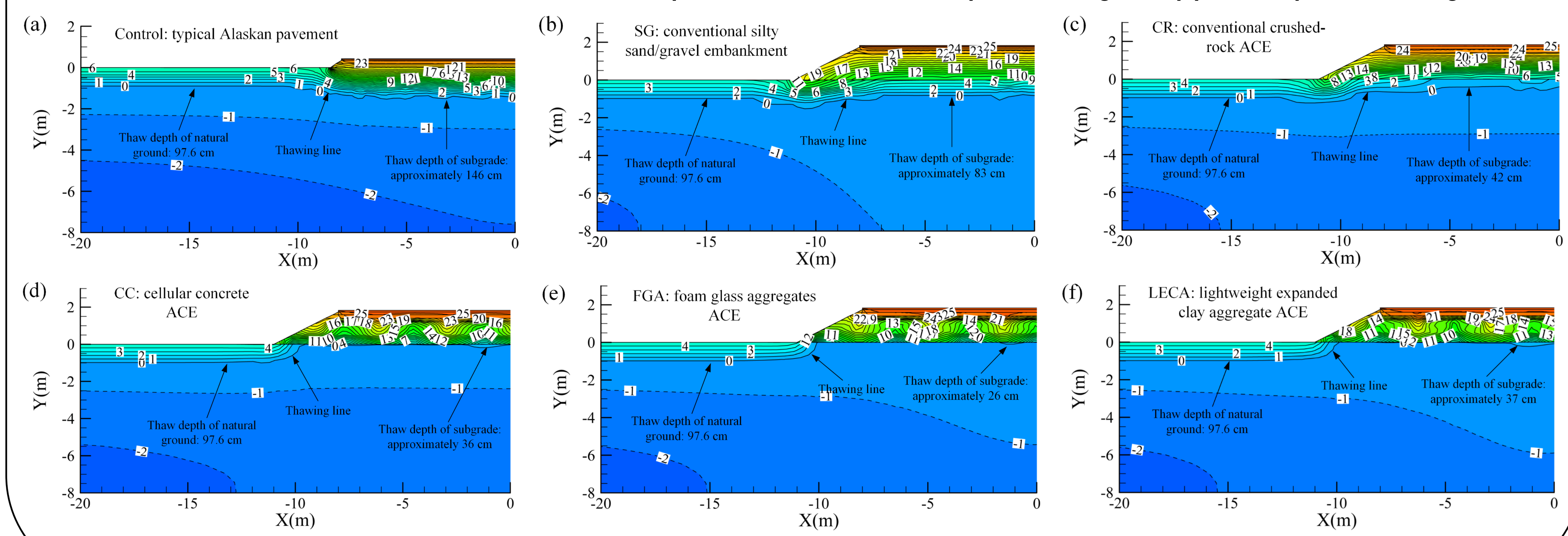
Natural convection in ACE.



The temperature difference between the bottom and top of HMA layers. (a) TEMPS. (b) ANSYS Fluent.



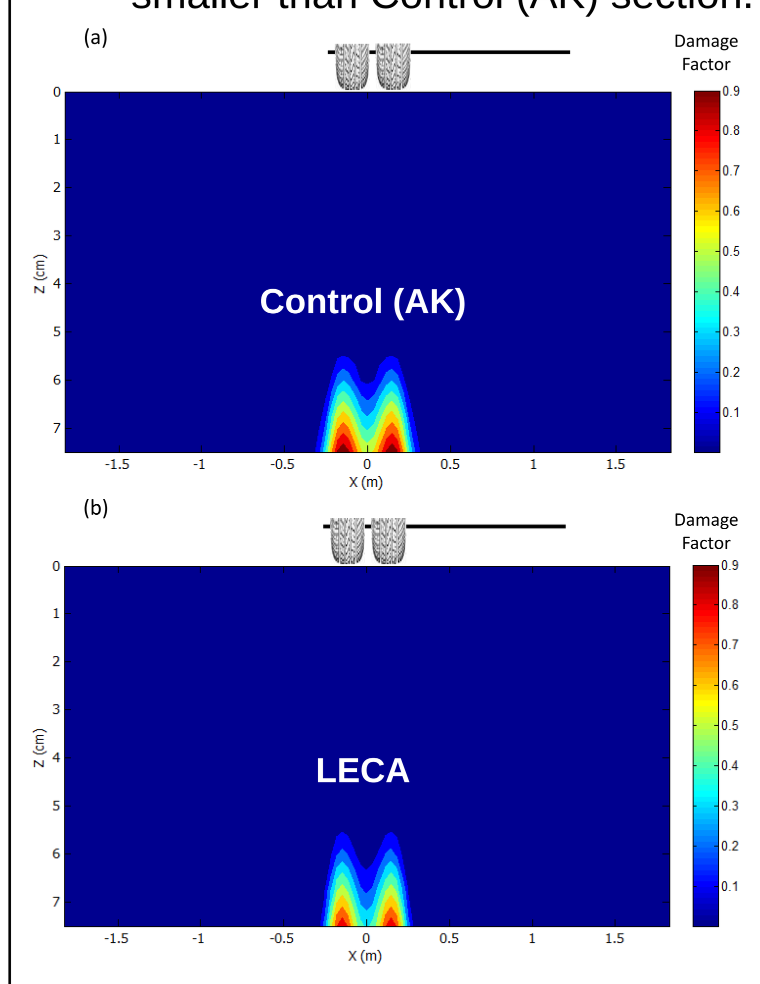
Temperature variation and thawing depth of subgrade by ANSYS Fluent. (a) temperature variation on the top of the subgrade. (b) thaw depth of the subgrade.



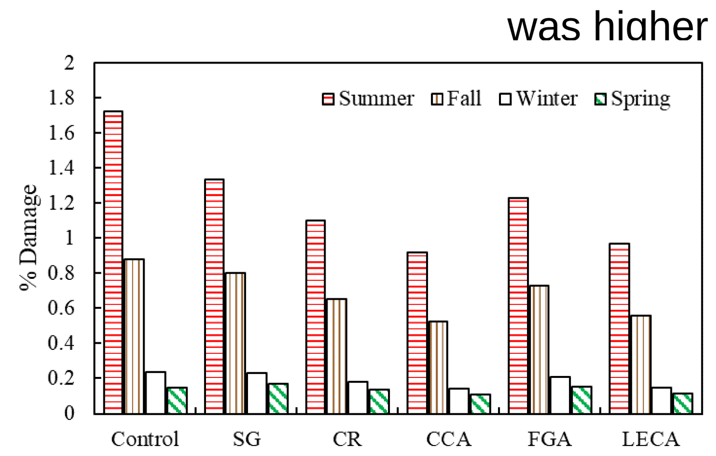
Instantaneous isotherms (℃) in summer (August 1) by ANSYS Fluent. (a) Control. (b) SG. (c) CR. (d) CC. (e) FGA. (f) LECA.

PAVEMENT STRUCTURAL RESULTS AND ANALYSES

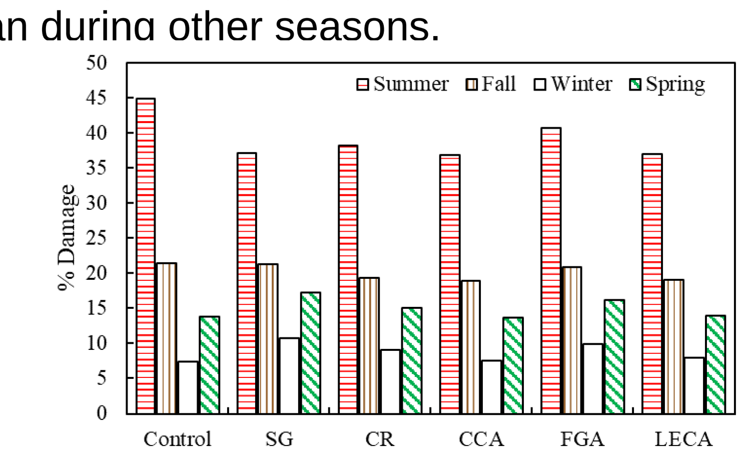
- After 1 million ESALs passed, the Control (AK) and SG sections exhibited the most fatigue damage.
- The damage factors and the damaged area in LECA is smaller than Control (AK) section.
- The seasonal effects were considered by FlexPAVE™ and AKFPD software.
- The damage developed during summer in all sections was higher than during other seasons.



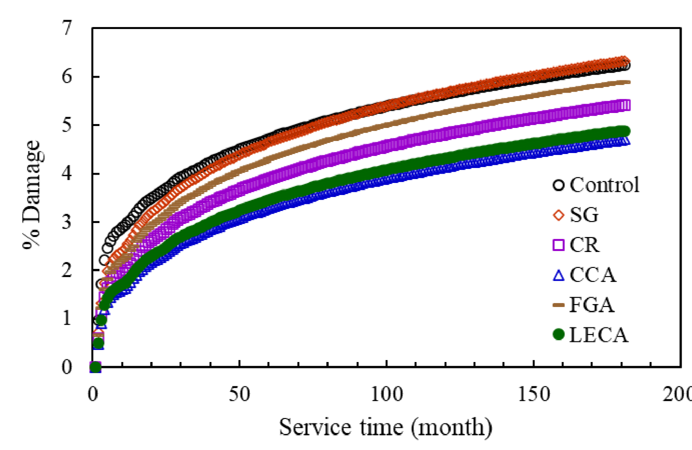
Fatigue damage contours of HMA layers at the end of Year 15 by FlexPAVE™.



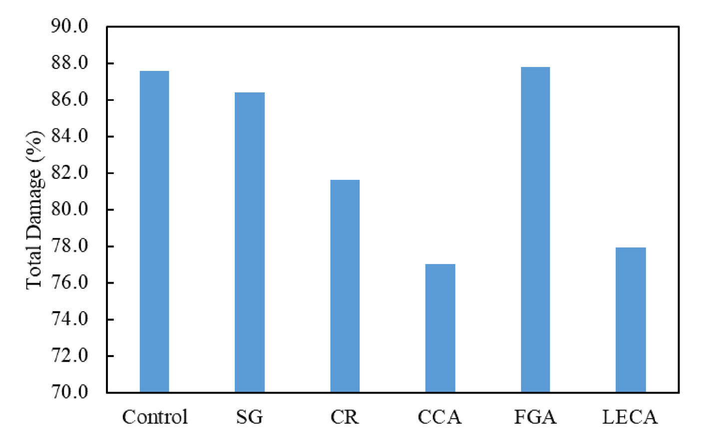
FlexPAVE™ predicted damage in each season in the first year.



AKFPD predicted accumulated damage in each season during entire design life.



Percentage fatigue damage of the HMA layers with different types of interlayers by FlexPAVE™.



Total damage from all seasons during the entire design life by AKFPD.

CONCLUSIONS

- Pavement structures with the proposed lightweight insulation layers could effectively reduce the temperature gradients of HMA layers, thereby mitigating the temperature curling caused cracking.
- ACE layer can significantly improve the road drainage and further mitigate the moisture warping of the HMA layer.
- Using lightweight aggregate ACEs can significantly reduce the temperature variation of the ice-rich subgrade and reduce the risk of thaw settlement of the subgrade.
- However, using foam glass aggregate in pavement should be very cautious due to its relatively low resilient modules.
- The applications of cellular concrete aggregate and lightweight expanded clay aggregate interlayers could effectively reduce the fatigue damage induced by the softening of the subgrade soils in hot seasons.

Low Carbon Technologies and Resilience for Long-Lasting Infrastructure

The 12th Annual Workshop of the International Association of Chinese Infrastructure Professionals (IACIP)

January 2022