RESEARCH CENTRE FOR RESOURCES ENGINEERING TOWARDS CARBON NEUTRALITY
±RCRE 碳中和資源工程研究中心

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

2022年ITASC智能交通智慧城市国际会议
生态智慧交通基础设施论坛暨生态道路专委会成立大会

Upcycling of Sewage Sludge Ash into Foaming Warm Mix Asphalt Additive
使用污泥焚烧灰制备发泡温拌沥青添加剂的增值再生技术

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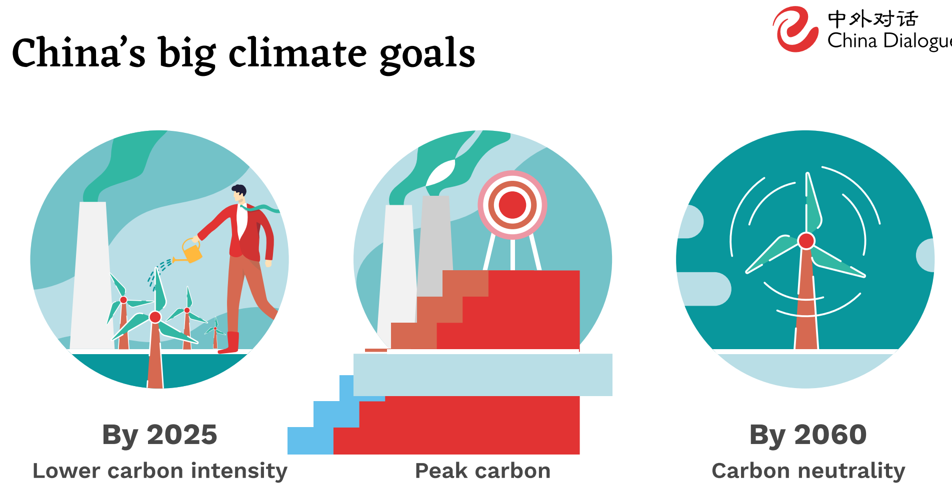
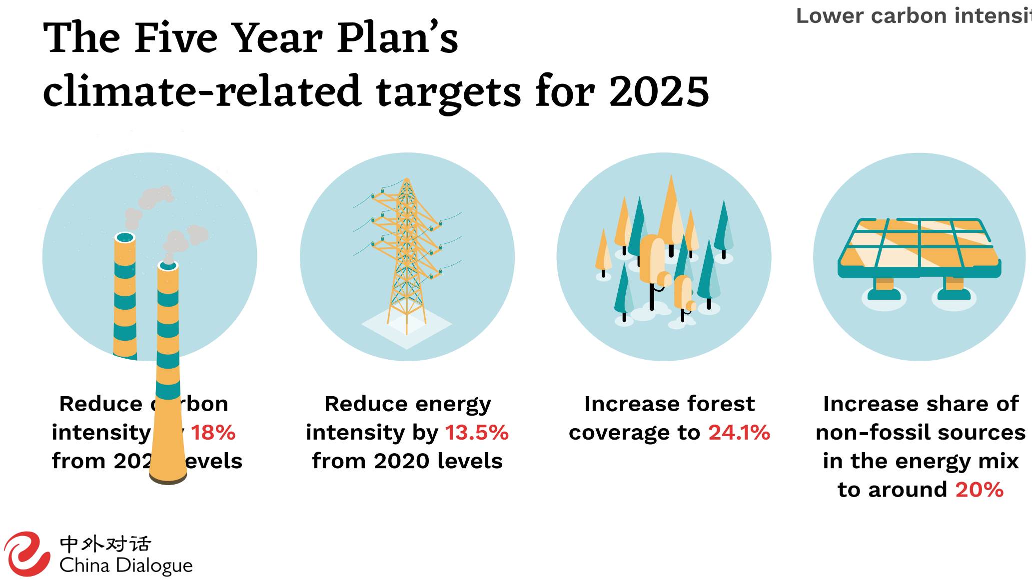
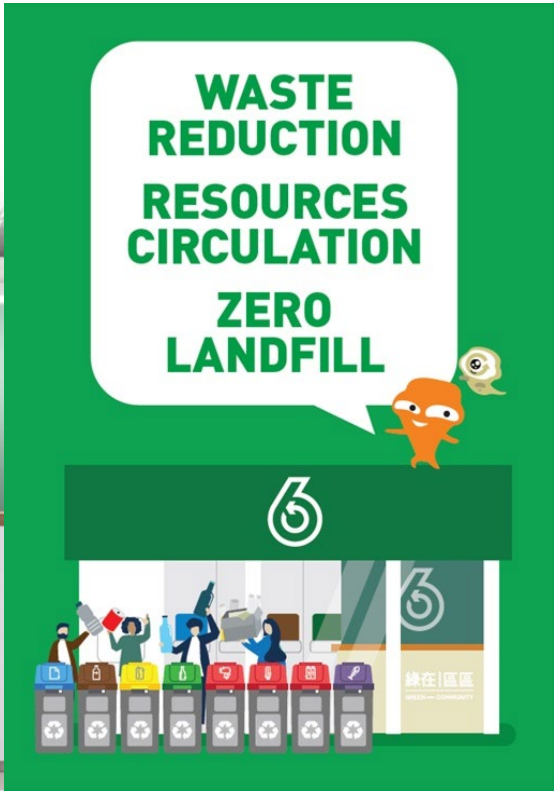
National Policy 14-5 Plan





Hong Kong Government Policy



"Looking ahead, to complement Hong Kong's target to strive for achieving carbon neutrality by 2050, we must proceed with low-carbon transformation more aggressively, develop more comprehensive supporting facilities for turning waste into resources or energy, build up a circular economy and support green employment opportunities. "

Turning Wastes into Sustainable Pavement Materials: Hong Kong’s Experience

Reclaimed Asphalt Pavement (RAP)

Waste Plastics: PET, PVC, PP, PE

Waste Tyre

Waste Glass

Biochar

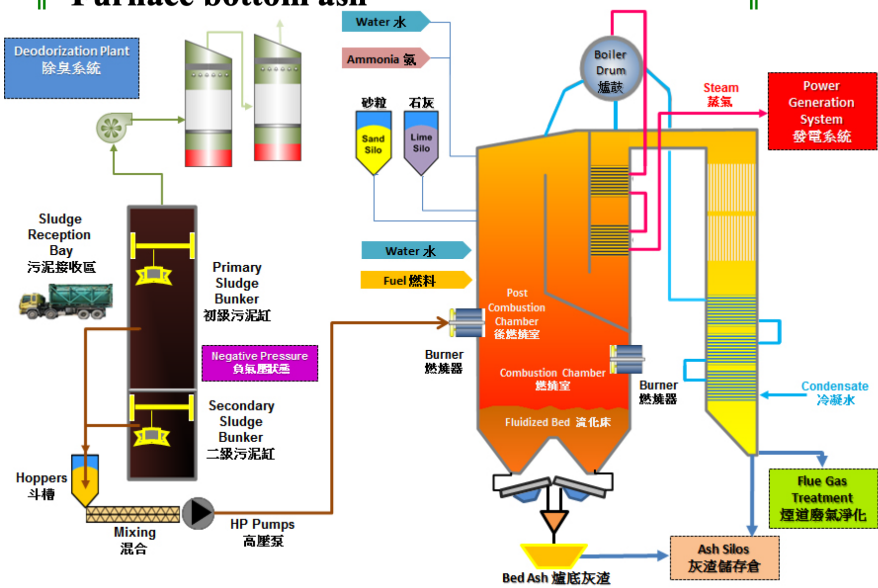
Sewage Sludge

The residual, semi-solid material that is produced as a by-product during sewage treatment of industrial or municipal wastewater.

Sewage Sludge & Sewage Sludge Ash (SSA)

Disposal of special waste at landfills in Hong Kong (EPD 2019)

Special waste type	Treatment method	Average daily quantity[1] (tpd)	
Chemical waste other than asbestos waste	CWTC	39	(-7.1%)
Clinical waste	CWTC	6	(7.4%)
Grease trap waste	WKTS[2]	499	(6.1%)
Horse stable waste	AWCP	26	(-0.4%)
Dredged mud and excavated materials	Marine dumping[3]	16,712	(-28.2%)
Dewatered sewage sludge[4]	Incineration at T · PARK	1,075	(1.6%)
Furnace bottom ash	Concrete manufacturing, stored in lagoon[5]	124	(3.1%)
	ete manufacturing, stored in lagoon[5]	1,263	(9.2%)

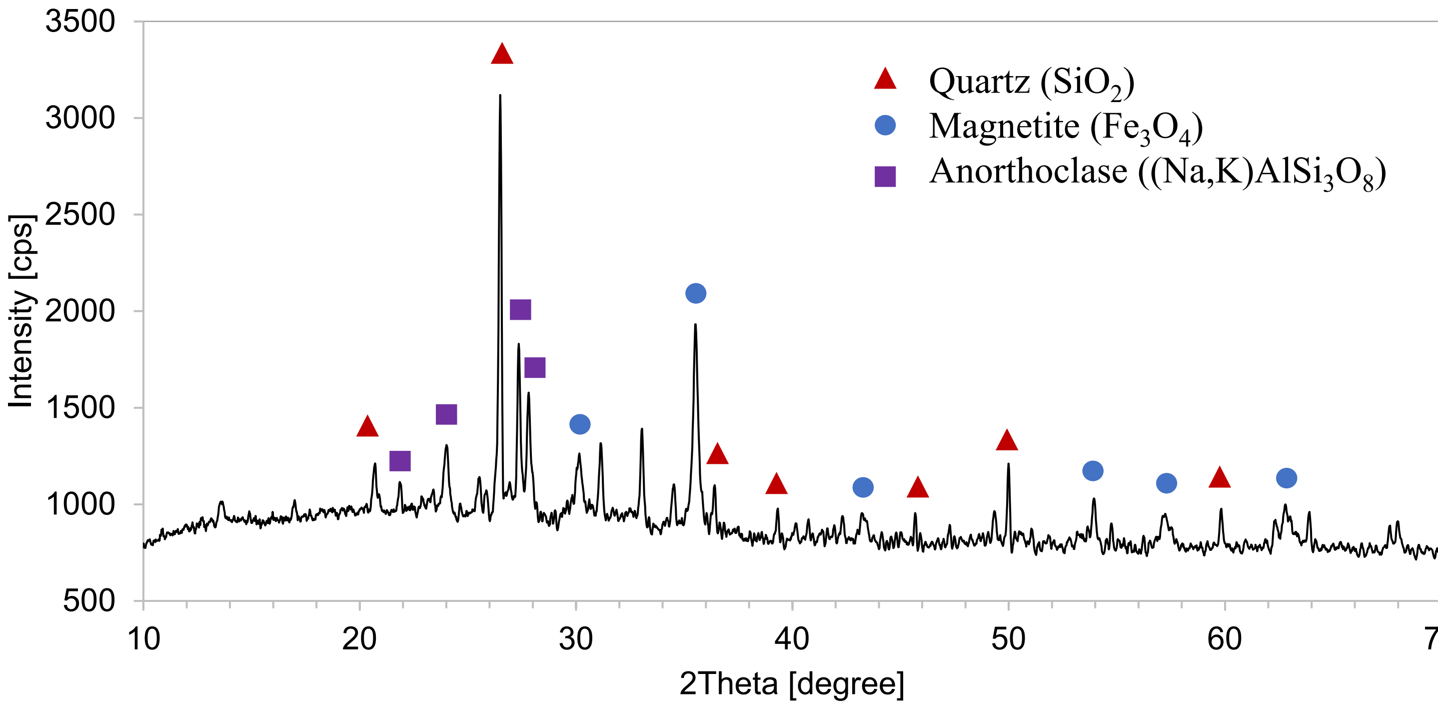


- The incineration of sewage sludge will lead to a volume reduction of 90%, and approximately 10% SSA.

Sewage Sludge Ash (SSA)

Chemical compositions and major crystalline phases of SSA

Compositions	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3
Percentage	33.9%	14.8%	16.5%	7.5%	2.6%	7.0%	2.9%	9.3%	3.7%



Warm Mix Asphalt (WMA)

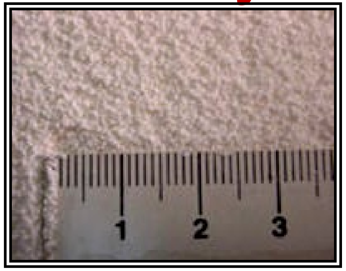
Chemical additives
- Surfactant

eg: Evotherm-DAT

Organic additives
- Wax

eg: Sasobit

Foaming additives
- Zeolite crystals

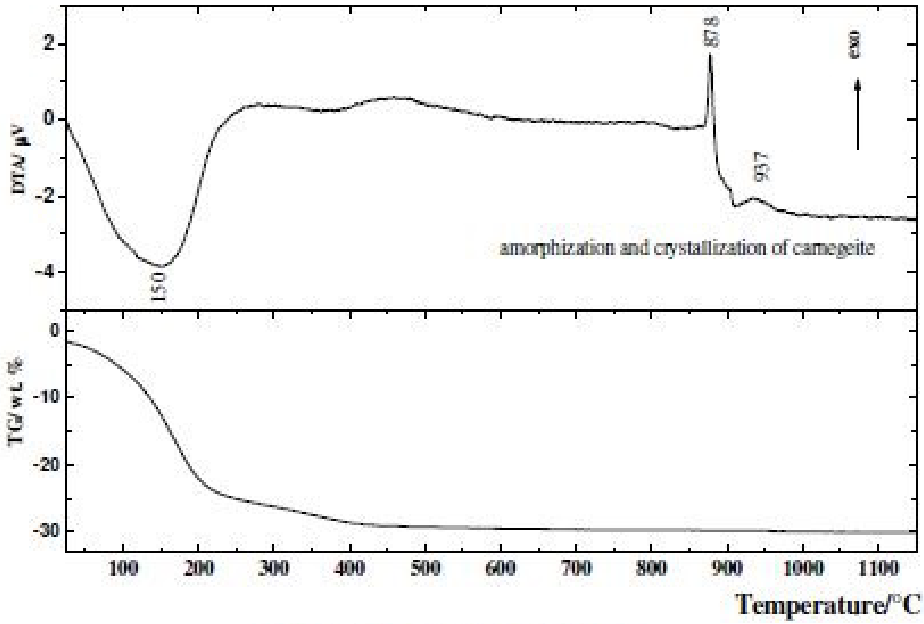


eg: Aspha-min

- Zeolites （沸石）are crystalline hydrated aluminium silicates
- When the target-type zeolite is added to asphalt mixture at a temperature of 100-200 ºC, the crystalline water will be released
- The release of crystalline water creates a volume expansion of asphalt binder that results in asphalt foam and improves workability and aggregate coating at lower temperatures

Critical Property of Target Zeolite

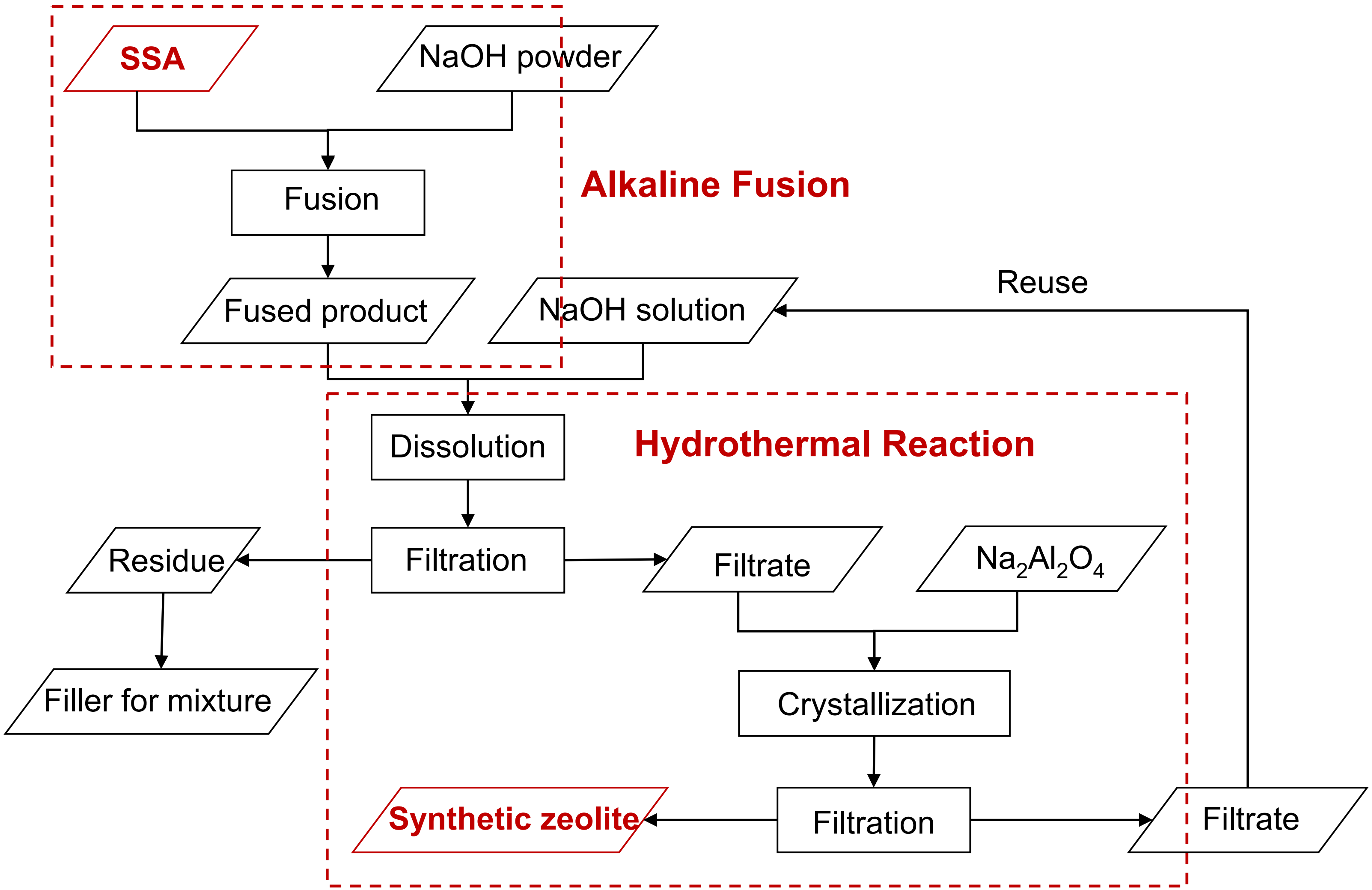
Target zeolite as a WMA additive: release crystalline water gradually at the construction temperatures of asphalt pavements. **Zeolite Linde Type A (LTA)**, $|Na_{96}(H_2O)_{216}|[Si_{96}Al_{96}O_{384}]$, can gradually release crystalline water between 100 and 200 ^oC.



TG and DTA curves of zeolite LTA

Tounsi H., Mseddi S., and Djemel S., "Preparation and characterization of Na-LTA zeolite from Tunisian sand and aluminium scrap", Physics Procedia 2 (2009) 1065-1074

Synthesis Process for Zeolite LTA

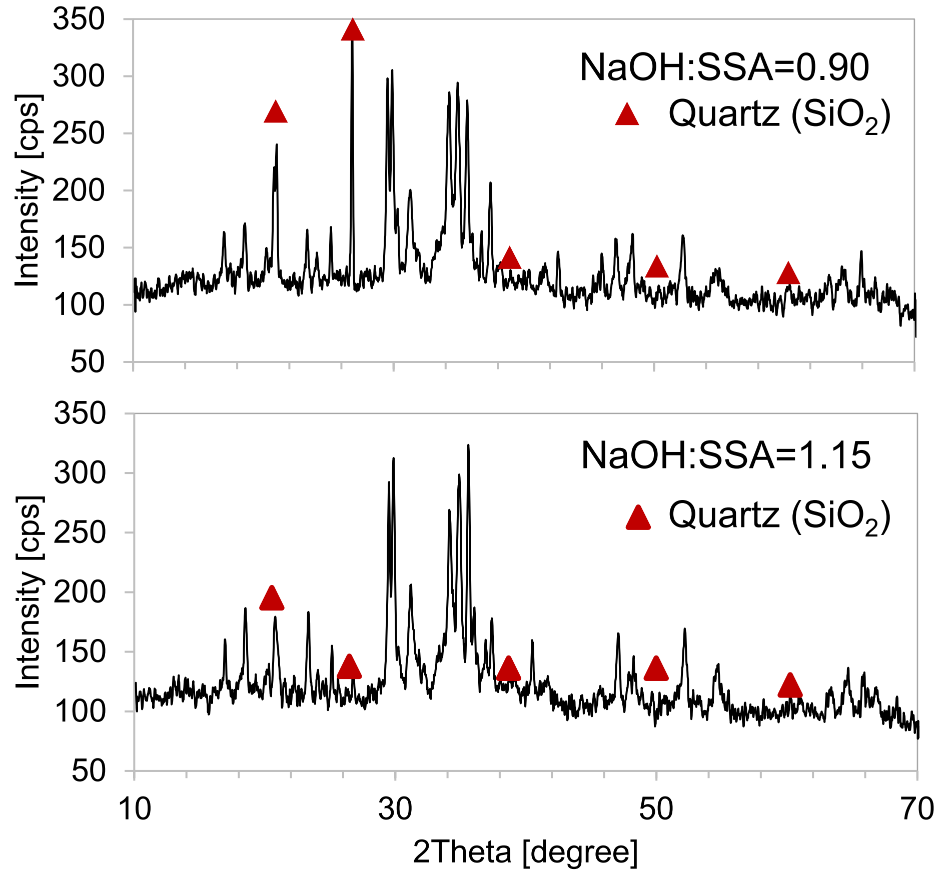


Y. Zhang, Z. Leng, L. Wang, S. Chen, C.W. Tsang, *Synthesis of zeolite A using sewage sludge ash for application in warm mix asphalt,* Journal of Cleaner Production, Vol. 172, Jan. 2018, pp. 686-695.

Alkaline Fusion and Control

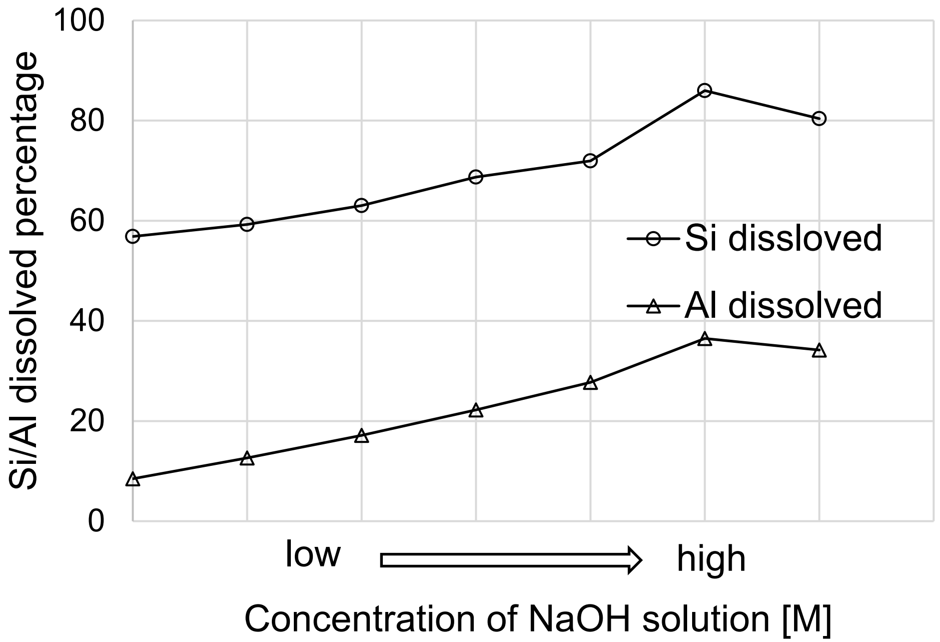
Alkaline fusion is used to convert quartz in SSA to silicates.

X-Ray Diffraction (XRD) patterns of fused products were used to detect the change of quartz, allowing determination of NaOH amount used in the fusion process.



Hydrothermal Reaction and Control

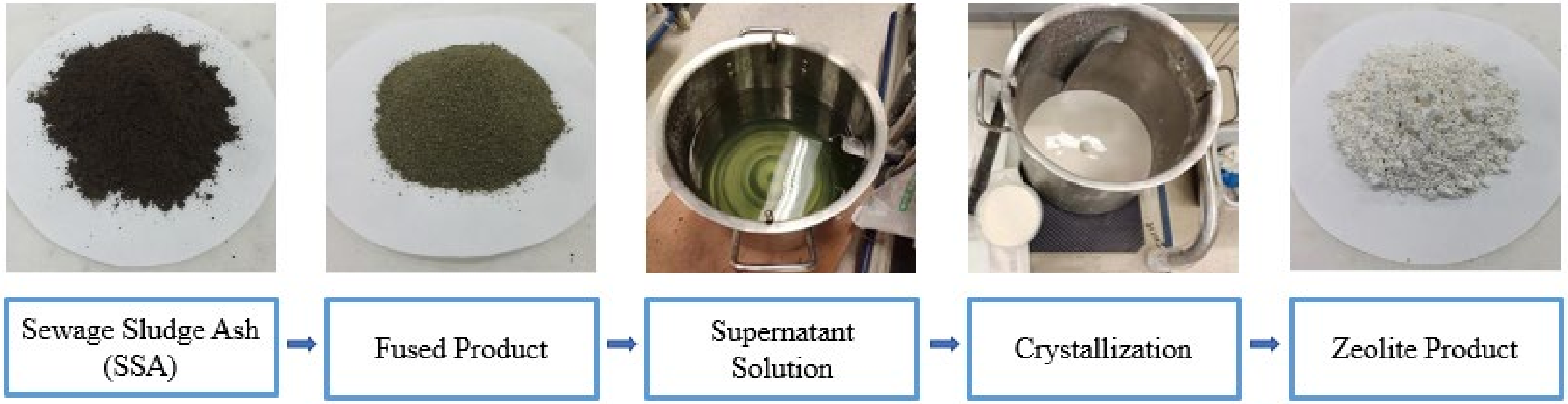
The Si and Al concentrations in the filtrate are measured using **Inductively Coupled Plasma (ICP) spectroscopy**, in order to determine the **concentation of NaOH solution** and adjust the **molar ratio of Si:Al** for hydrothermal reaction.



Hydrothermal Reaction and Control

Experimental designs are created to determine the optimum values for Si:Al molar ratio, crystallization temperature and period. The yield of synthetic zeolite, combined with its thermal properties (water loss percentage), are selected as the quality indices to optimize the reaction conditions.

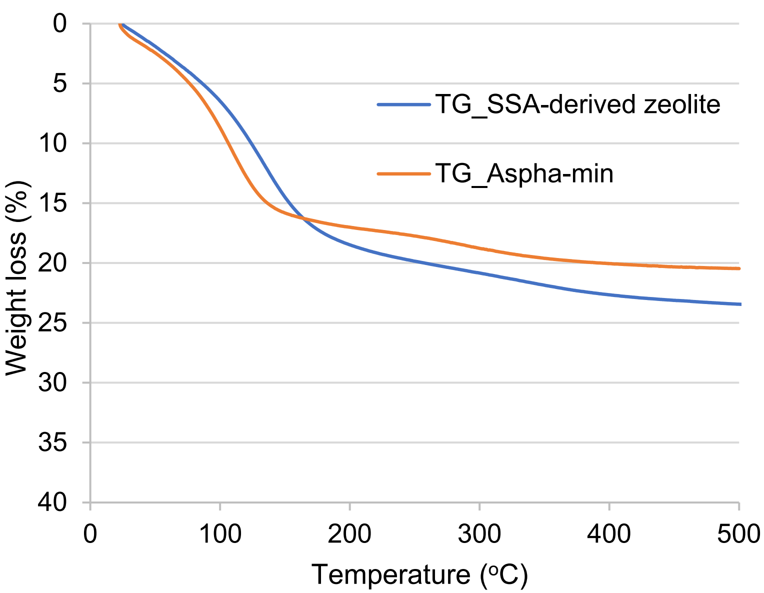
Optimum conditions: Si/Al = 0.8; Temperature: 80 °C, Period: 3 h.



Recycling of waste SSA into WMA additive zeolite

Thermal Properties and Crystal Phase

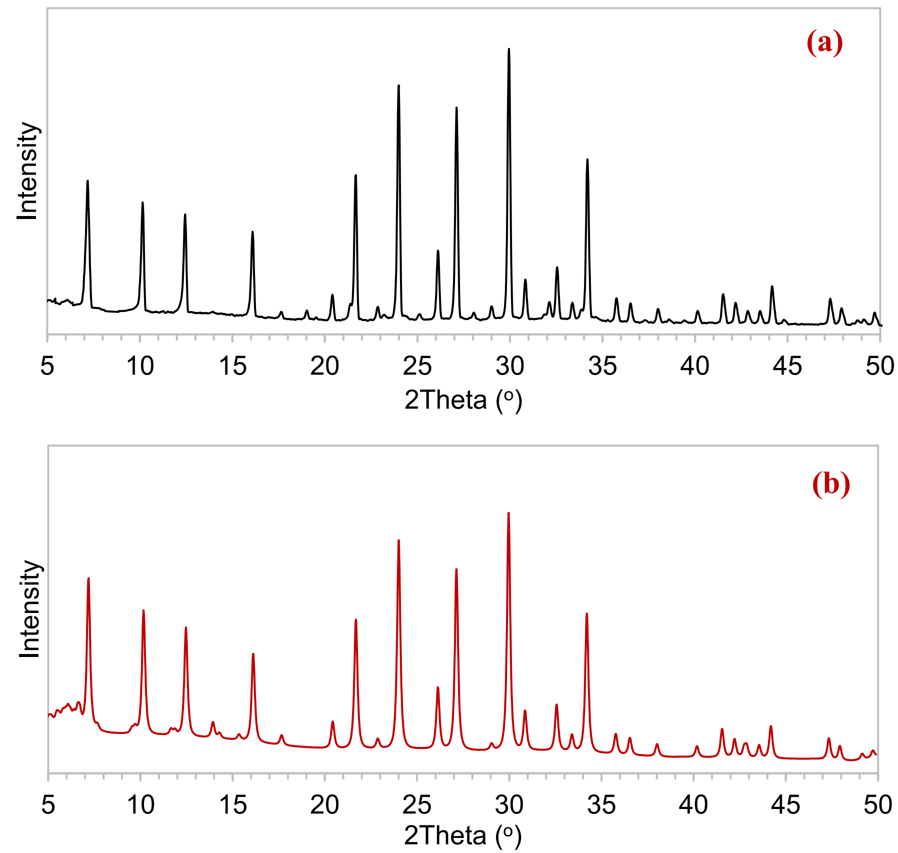
Comparison of thermal behaviors of SSA-derived zeolite and Aspha-min



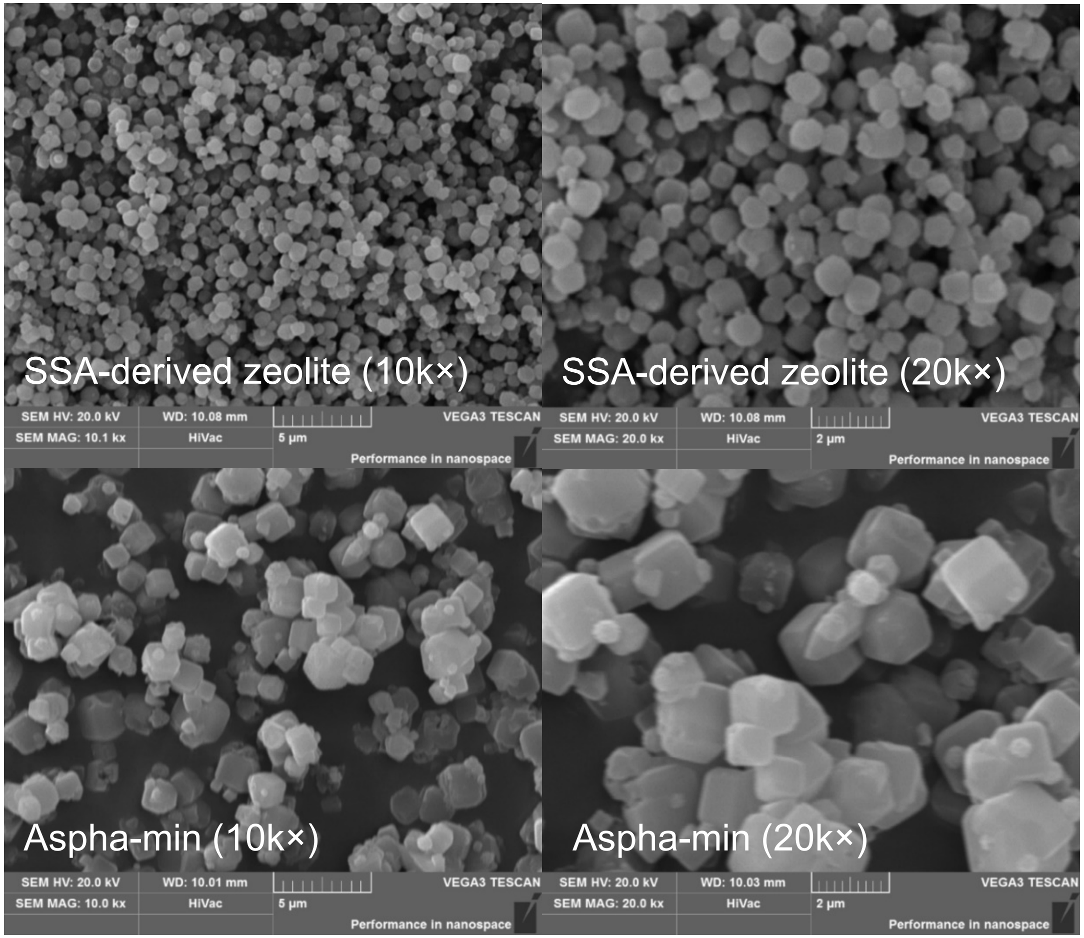
SSA-derived zeolite

Commercial zeolite additive: Aspha-min

XRD patterns of: (a) SSA-derived zeolite; and (b) Aspha-min



Morphology of Synthetic Zeolites



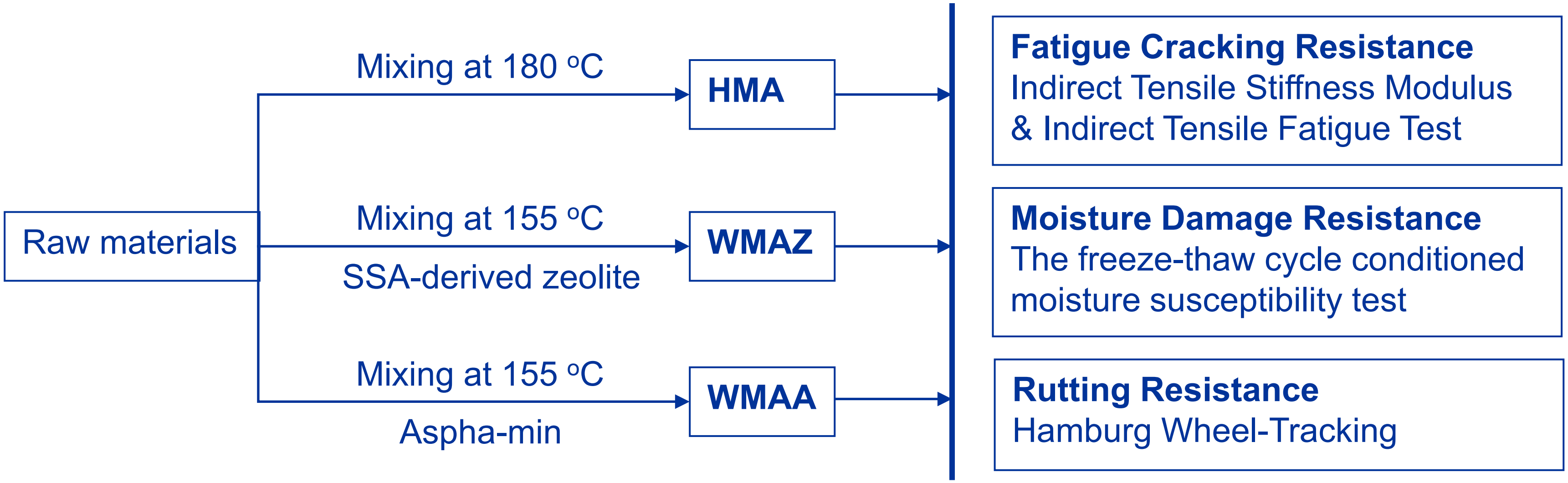
SEM images of SSA-derived zeolite and Aspha-min

Performance of Synthetic Zeolite in WMA

Experimental Plan

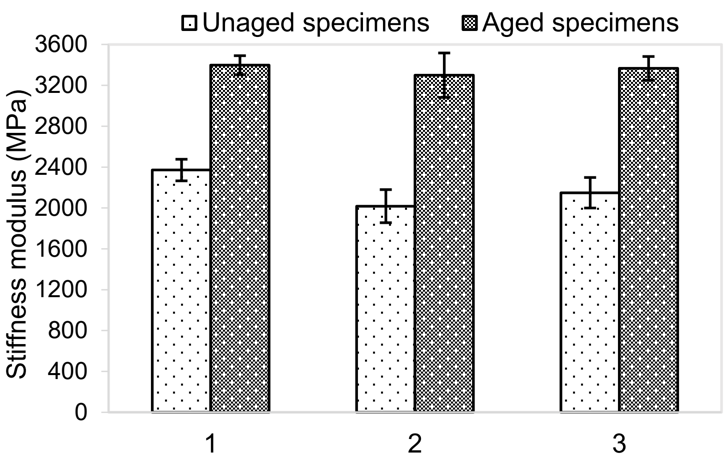
Mixture types: conventional **hot mix asphalt (HMA), warm mix asphalt with SSA-derived zeolite (WMAZ)**, and **warm mix asphalt with Aspha-min (WMAA)**

Materials: Polymer Modified Stone Mastic Asphalt with a nominal maximum aggregate size of 10 mm (**PMSMA10**), binder content was 6% (PG76 binder) by the total mass of the mixture. The dosage of WMA additives was 0.3% by the total weight of the mixture.

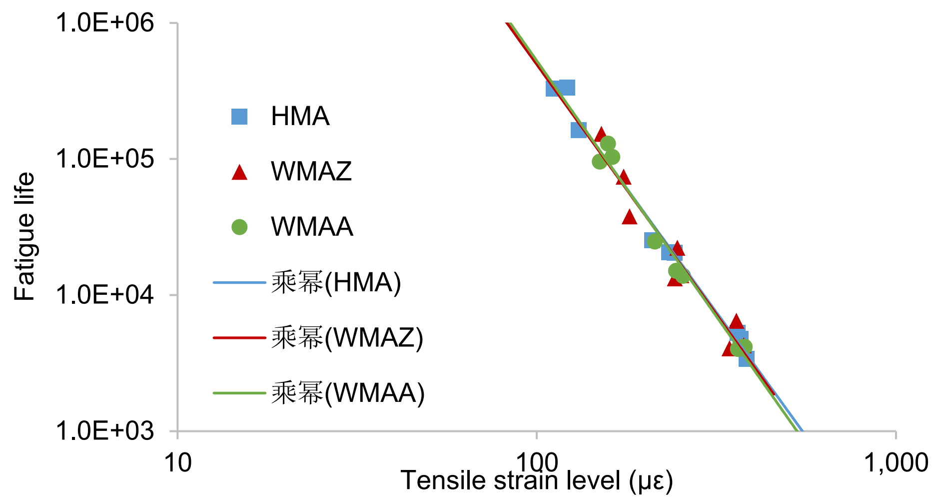


Fatigue Cracking Resistance

Results of the ITSM Tests



Fatigue Lives vs Initial Strain

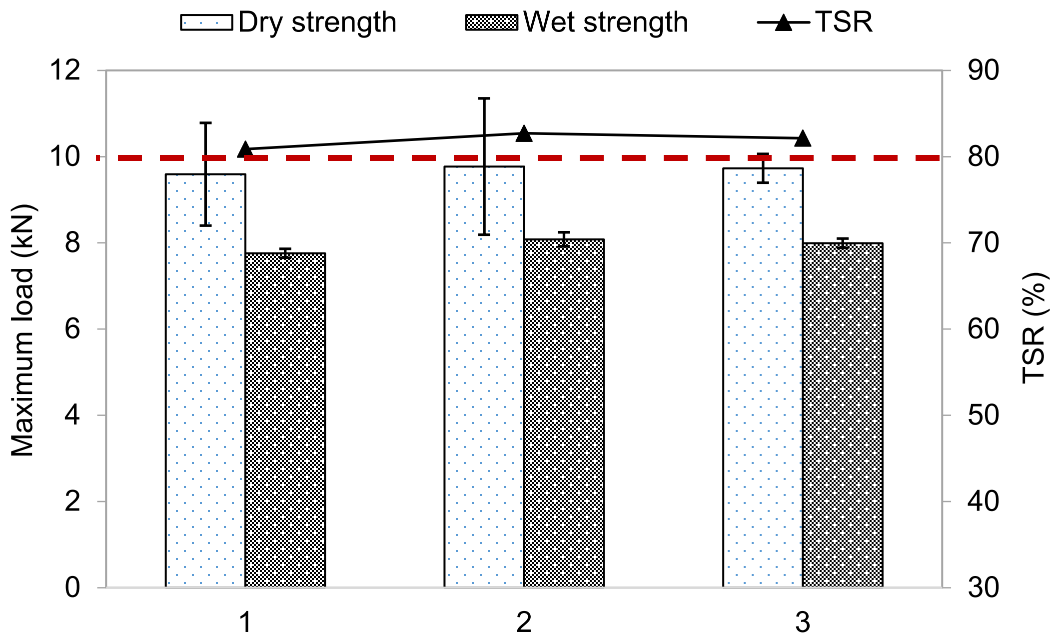


Before aging, WMA mixtures showed lower stiffness modulus than the HMA mixture. Such differences became insignificant after aging.

All mixtures showed similar resistances to fatigue cracking, and there was no significant difference observed in their fatigue lives.

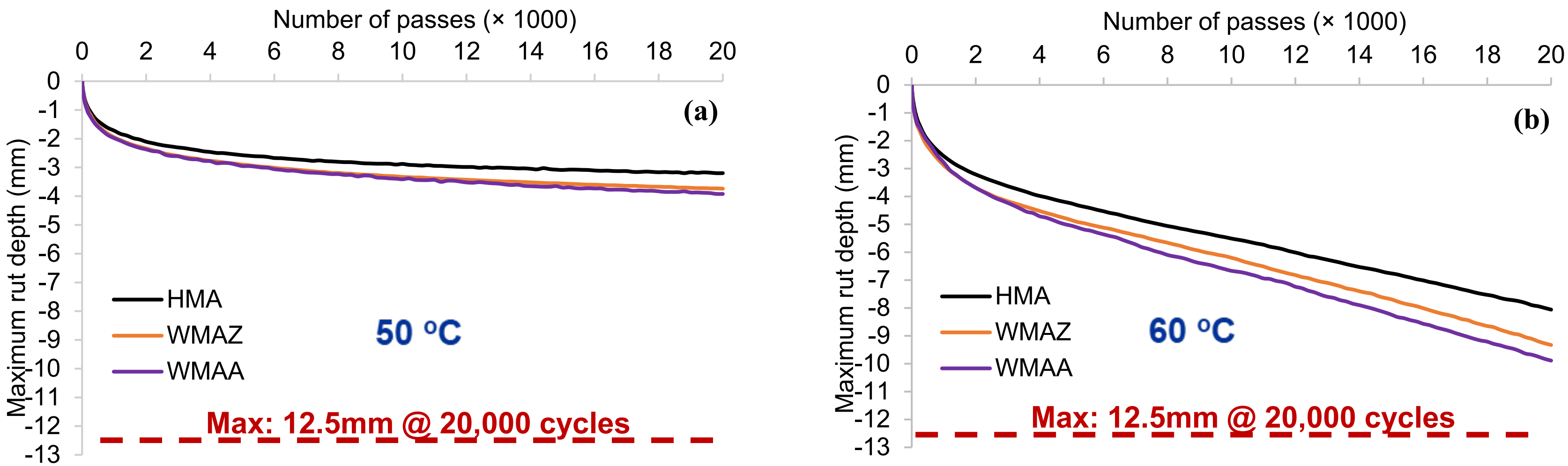
Moisture Damage Resistance

Results of the Tensile Strength Tests



- **WMAZ had the highest strength both before and after conditioning, but the difference is not significant.**
- **The Tensile Strength Ratio (TSR) results suggested that there is no specific concern about the moisture susceptibility of all the three mixtures.**

Rutting Resistance



Hamburg wheel-tracking curves of HMA and WMA mixtures at: (a) 50 °C; and (b) 60 °C

Mixture	Test Temperature (°C)	Creep Slope (mm/ 1000 passes)	Max Rut Depth (mm)
HMA	50	0.061	3.20
WMAZ		0.078	3.74
WMAA		0.086	3.92
HMA	60	0.269	8.06
WMAZ		0.314	9.33
WMAA		0.344	9.89

Findings

- Zeolite LTA can be successfully synthesized from created from SSA through alkali fusion and hydrothermal reaction.
- Thermal (water loss) properties of the synthetic zeolite meet the requirement for zeolite to be used as a WMA additive.
- The synthetic zeolite from SSA can reduce the construction temperature of asphalt mixtures for 25 ºC.
- The overall engineering performance of the WMA mixture with SSA-derived zeolite additive was similar to that of the HMA mixture and superior to that of the WMA mixture with the commercial foaming additive, Aspha-min.

Remarks

- Appropriate recycling/upcycling of wastes into pavement is a sustainable practice towards carbon neutrality, which helps address not only the waste problem but also the concern of the diminishing virgin materials for pavement construction.
- Critical questions to reflect and address:
  - Suitability of a given waste, i.e., waste selection
  - Variability of wastes, its effects, and quality control
  - Waste pre-treatment methods: mechanical, chemical, thermal,..
  - Methods to add wastes to pavement materials during construction
  - Long-term performance/ environmental impacts of waste incorporated pavements
  - …

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Thank You!

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