Recycling Plastic Wastes as Reinforcing Fibers in Asphalt Pavements

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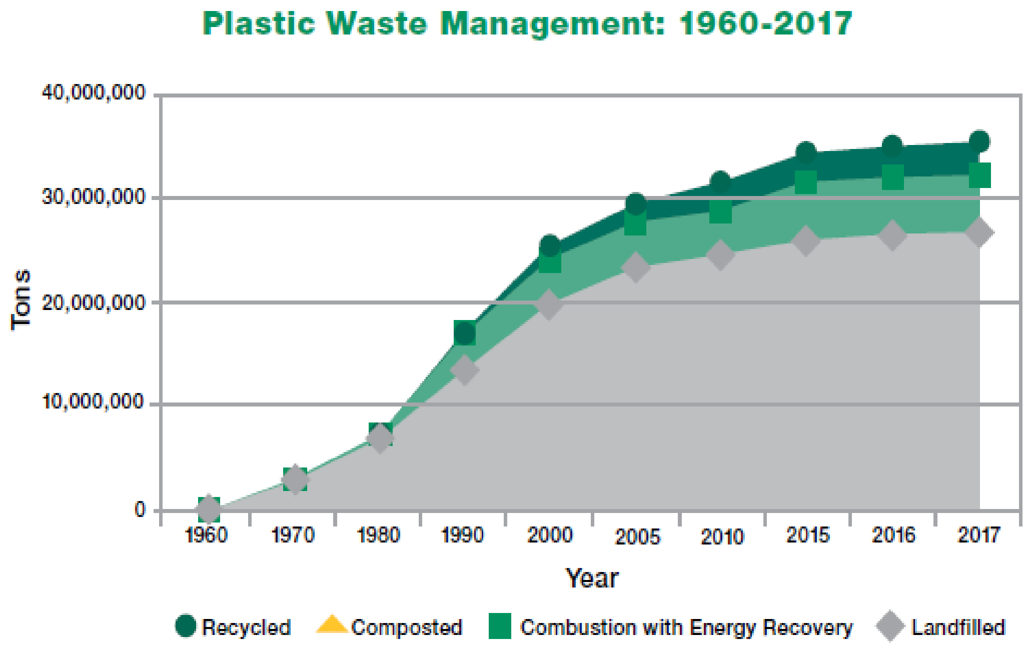
Background

- **40 million tons** of plastic waste in the U.S. in 2021.
- **Only 8.4%** (3 million tons) of the plastic waste are recycled.



EPA. 2020

Type	Sources	Example	Ratio of Plastic Waste (%)
LDPE	Soft water bottles		17.5
HDPE	Plastic bottles		11.7
PP	Straw, furniture		32.1
PVC	Pipes		2.8
PET	Soft water bottles		7.3
PS	Plates and cups		4.9
Nylon	Fishing net		< 23

Background

- Recycling plastic waste into asphalt pavement
  - **Wet Process**: Plastic wastes are used as **binder modifiers**.
  - **Dry Process**: Plastic wastes are incorporated as **fine aggregate replacement**.

Method	Advantage	Drawback	Used Plastic
Wet Process	Normative guidance, Higher stiffness and viscosity, rutting resistance	Poor storage stability, **Segregation**, **Generating toxic fumes**, Complex production process	LDPE, HDPE, PP, PVC
Dry Process	Lack of normative guidance, Rutting resistance	**Generating toxic fumes**, Poor water stability, high energy consumption	PET, Nylon

Figure 1– Wet Process

Figure 2 – Dry Process, plastic (left), fine aggregate (right)

Figure 1 – R. Willis, F. Yin, R. Moraes. (2020), Figure 2 – M.A. Dalhat (2019), Xu (2021)

Problem Statement

- **Drawbacks** of current methods
  - Wet process: Poor storage stability, segregation, generating toxic fumes
  - Dry process: Generating toxic fumes, high energy consumption

- Third method: **Recycling plastic** wastes as **fibers** in asphalt pavements.

Figure 3 – Plastic Waste

Figure 4 – Aramid Fiber

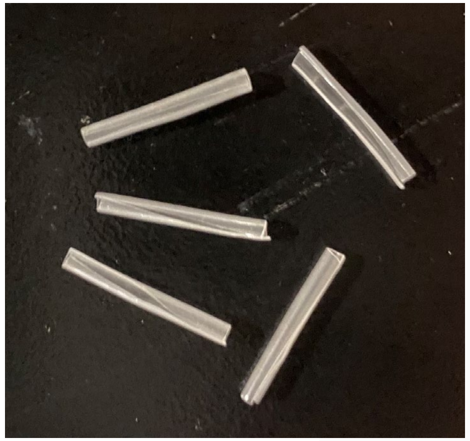


Figure 5 – PET Fiber

Figure 4 – Kaloush, K. E (2010),

Advantage of Fiber in Asphalt Pavement

- Fiber-reinforced asphalt
- Type of fiber
  - Glass fiber, Aramid fiber, Carbon fiber, Polyester fiber, Polyamides fiber, Polyacrylonitrile fiber, Polypropylene fiber
- Advantage
  - Fibers increase the crack resistance by having the behavior of (a) **pulled-out** and (b)**bridging**

Figure 6 – Example of Crack in Asphalt Pavement

Figure 7 – Aramid Fiber

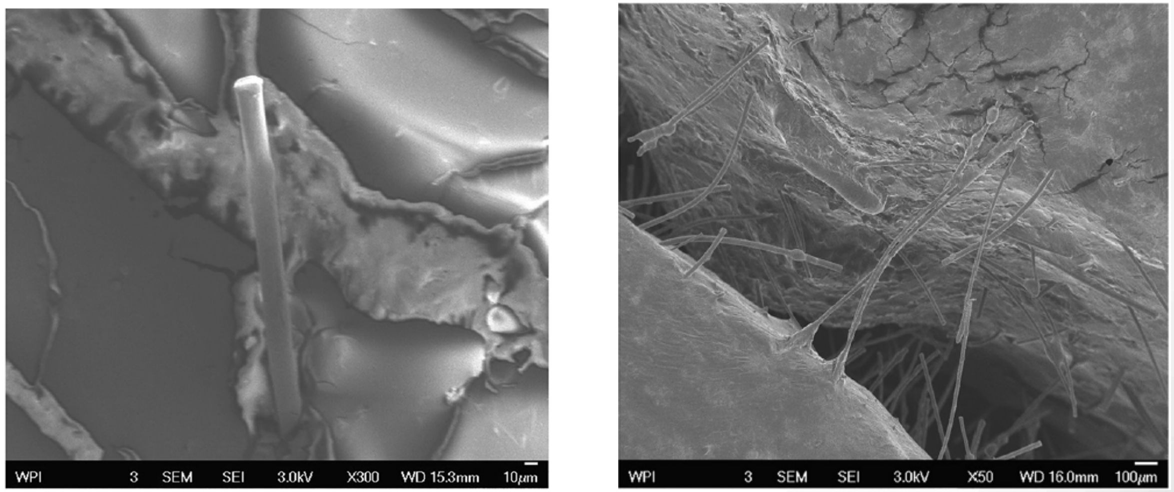


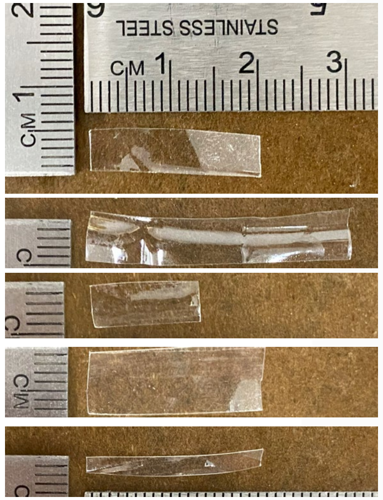
Figure 8 – Image of fiber with pull-out behavior (left), Image of fiber with bridging behavior (right)

Figure 6 – T. Ahmad. (2018), Figure 7 – Kaloush, K. E (2010), Figure 8 – Jia *et al*. (2023)

Experiment Scenario

- Plastics with high melting points were selected for plastic fibers: **PET**, **Nylon**

Scenario	Type	Thick [mm]	Length [mm]	Weight %
1	Control	N/A	N/A	N/A
2	**PET**	5	20	0.4
3	PET	5	30	0.4
4	PET	5	10	0.4
5	PET	8	20	0.4
6	PET	2	20	0.4
7	PET	5	20	0.6
8	PET	5	20	0.2
9	**Nylon**	N/A	17	0.4

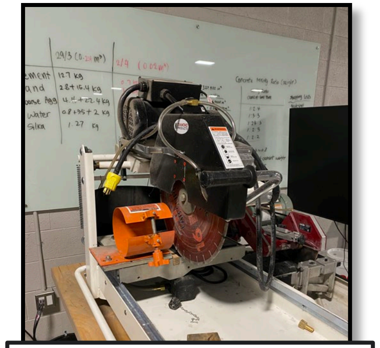


Specimen Preparation

- Standard testing method, **ASSHTO T393**, was used to prepare specimen.

Mixing temperature:
157 °C (315 °F)

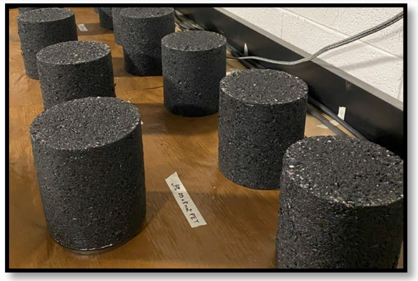
Height: 160 mm
Angle: 1.16°
Pressure: 600 kPa



Thickness: 50±1 mm
Notch depth: 15±1 mm

Temperature:
25°C, 1°C, -12°C

Mixing | Compaction | Fabrication | Conditioning



ASSHTO: American Association of Highway and Transportation Officials

Fracture Testing

Temperature	Thickness [mm]	Loading Control	Loading Rate [mm/min]	Analyzed Data	Reference
25°C	50±1	LLD	**50**	G_f, m, FI	AASHTO Standard: T393 (I-FIT)
1°C	50±1	LLD	**2.0**	G_f, m, FI	Haslett, Katie E., (2018)
-12°C	50±3	LLD	**0.3**	G_f, m, FI	AASHTO T394 (SCB); EN 12697-44:2010; Yang, S., (2021)

- LLD: Load-Line Displacement
- G_f: Fracture Energy
- FI: Flexibility Index
- m: Post-peak slope

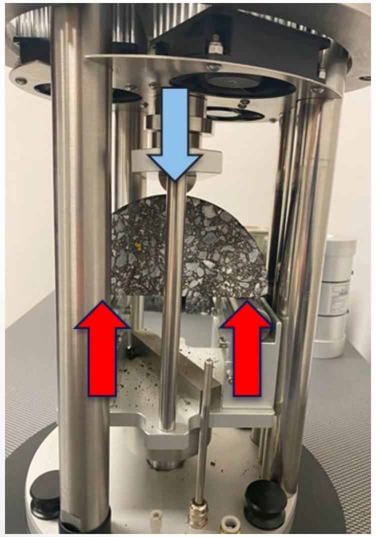


Figure 9 – I-FIT fracture testing

Figure 10 – Asphalt sample after fracture

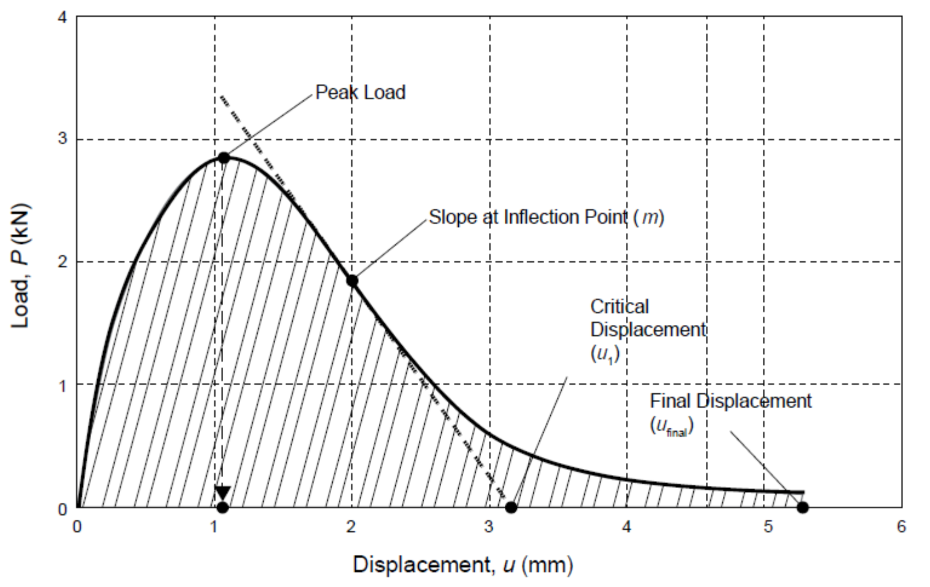


Figure 11 – Load-displacement curve used for analysis

Effect of PET Fiber

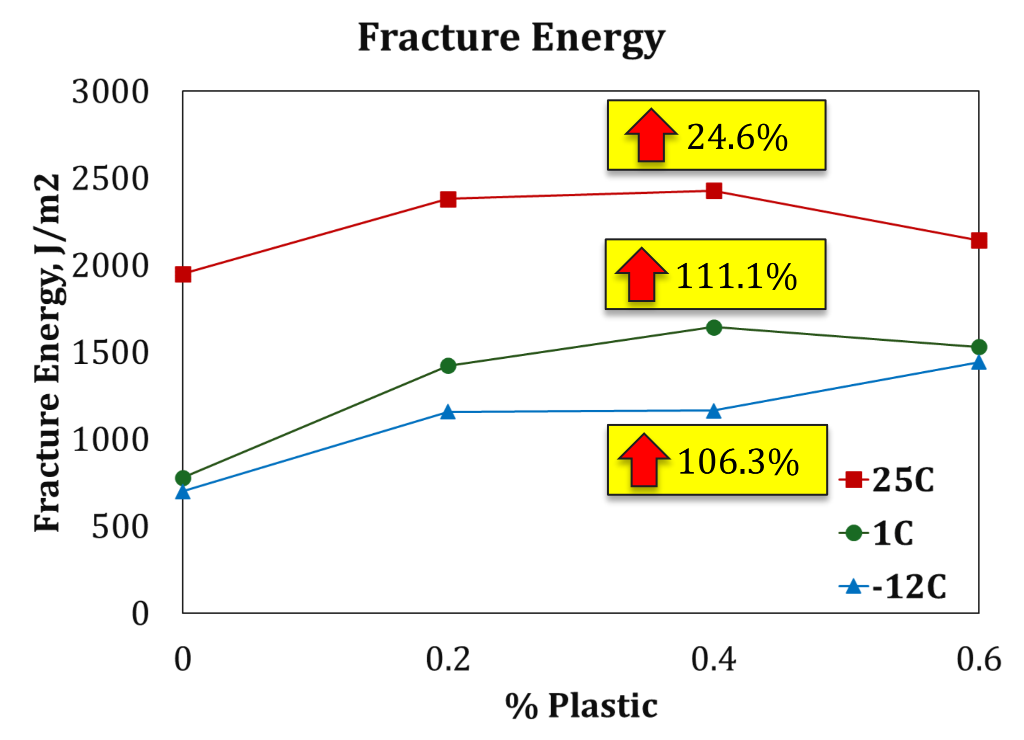
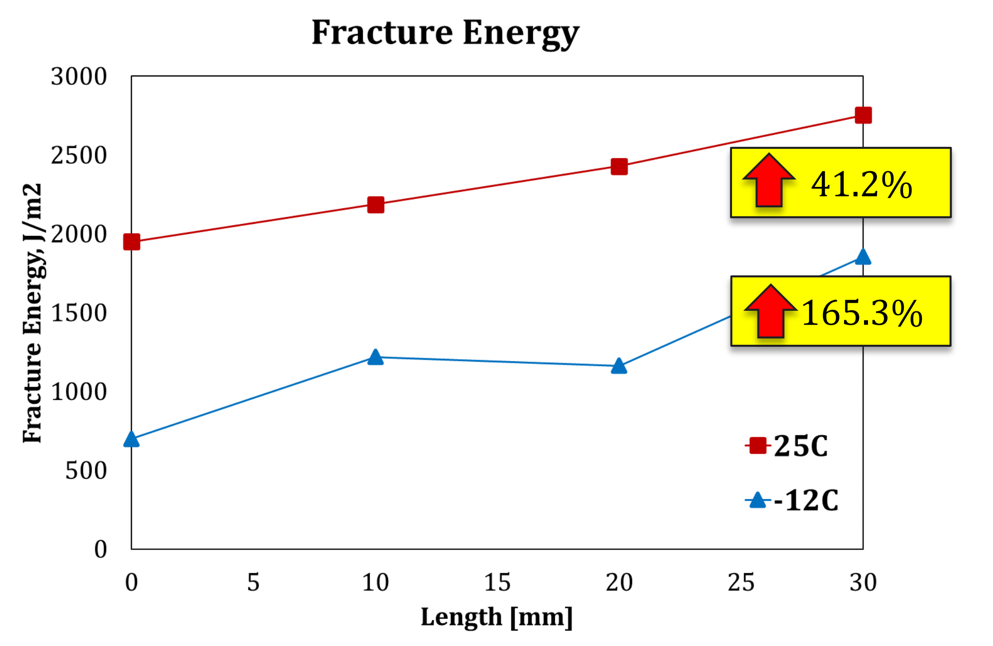


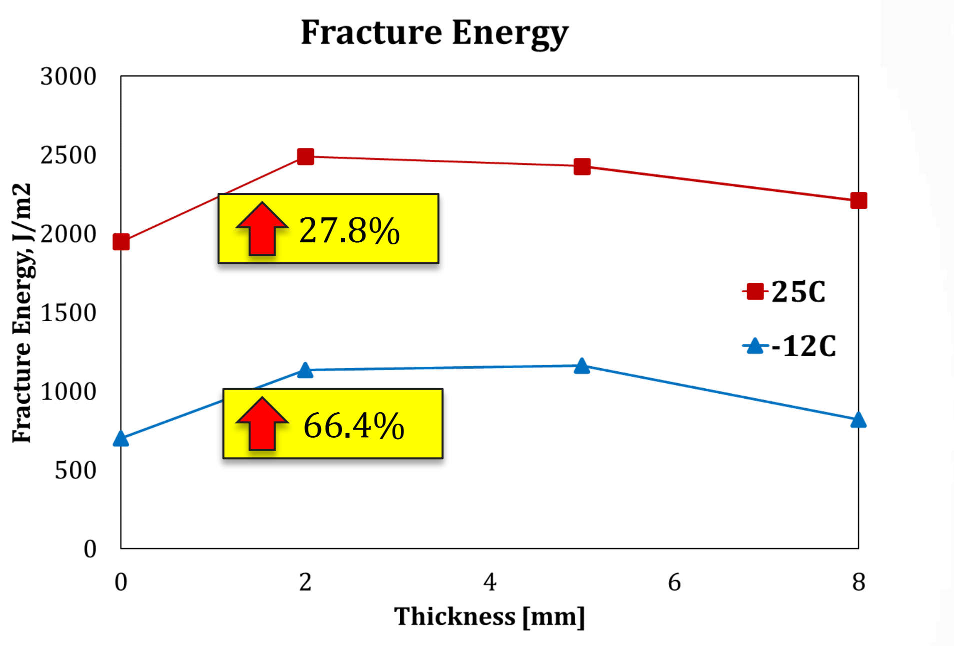
Figure 11 – Pulled out fibers at high temperature

Figure 12 – Broken fiber at low temperature

- Fracture Energy (G_f)
  - At 25°C, fracture energy **increased by 24.6%.**
  - At 1°C, fracture energy **increased by 111.1%.**
  - At -12 °C, fracture energy **increased by 106.3%.**

Effect of PET Fiber Size on Fracture Energy



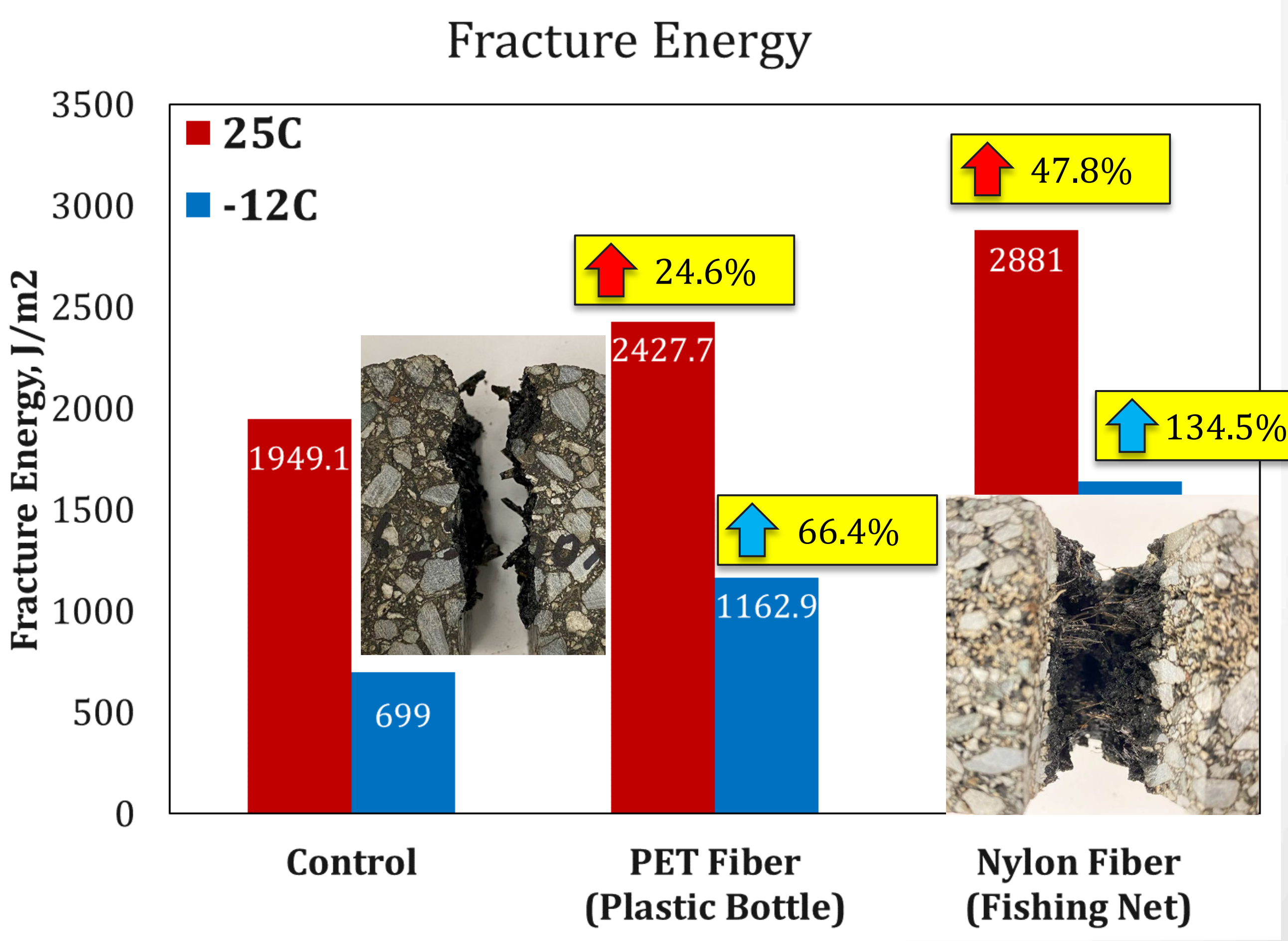


- The **longer** plastic fiber requires more energy to fracture the specimen.
- The **thinner** plastic fiber requires more energy to fracture the specimen because thicker fibers decrease adhesion between aggregates and binder.

FI	Control	30mm*5mm	20mm*2mm
25°C	2.62	5.82	3.26
-12°C	0.02	2.05	0.11

Effect of Different Types of Plastic

- Fracture Energy (G_f)
  - At **25°C**, Fracture energy increased by **25% with PET** fibers and by **48% with Nylon** fibers.
  - At **-12°C**, Fracture energy increased by **66% with PET** fibers and by **135% with Nylon** fibers.
  - The behavior of **pull-out** and **bridging** can be identified.



- Flexibility Index (FI)

FI	Control	PET	Nylon
25C	2.63	9.15	8.28
-12C	0.02	0.09	0.12

Conclusion

- **Recycling plastic wastes as fibers** in asphalt pavement has the potential to improve its performance by reinforcing crack resistance.
- It seems that the plastic fiber **performs better at low temperatures** with the behavior of **fiber breakage**.
- **Longer and thinner fiber** shape is recommended to improve crack resistance.
- The fracture energy with the **nylon fiber was more significant** than PET fiber.

Further Research

- **Plastic properties** after heat treatment need to be identified.

- Identify the **optimum amount and size of fiber** to improve asphalt performance.

- Identify the **friction coefficient** between plastic fiber and asphalt binder.

Acknowledgement

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Questions?

Thank you for listening!