Project Notes:

Project Title: Simulating Recycled Polyethylene-Terephthalate Warm Mix Asphalt
Name: Shi, Charles

Note Well: There are NO SHORT-cuts to reading journal articles and taking notes from them. Comprehension is paramount. You will most likely need to read it several times, so set aside enough time in your schedule.

Contents:

Knowledge Gaps:

This list provides a brief overview of the major knowledge gaps for this project, how they were resolved and where to find the information.

Knowledge Gap	Resolved By	Information is located	Date resolved
Basic materials needed to make concrete	Professional Help	Notes App on iPhone	10/1/25
Basic materials needed to make asphalt	Professional Help	Notes App on iPhone	10/3/25
Flexural Strength Test			
Best Water/Cement Ratio			
Maintenance			
Transportation			
Sourcing Resources			

Literature Search Parameters:

These searches were performed between (Start Date of reading) and XX/XX/2019.
List of keywords and databases used during this project.

Database/search engine	**Keywords**	**Summary of search**
Google Scholar	Plastic Asphalt Concrete SMA TOPS CMA	To find articles based on my topic + find researchers
ScienceDirect	Plastic Asphalt Concrete SMA TOPS	To find articles based on my topic

Tags:

Tag Name	
#concrete	#recycling
#PET	#plastic
#properties	#asphalt
#SMA	#email
#summer	#design
#CMA	#WMA

Article #1 Notes: Title

Article notes should be on separate sheets

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Source Title	
Source citation (APA Format)	
Original URL	
Source type	
Keywords	
#Tags	
Summary of key points + notes (include methodology)	
Research Question/Problem/ Need	
Important Figures	
VOCAB: (w/definition)	
Cited references to follow up on	
Follow up Questions	

Article #1 Notes: On the mechanical properties of concrete containing waste pet particles

Article notes should be on separate sheets

Source Title	ScienceDirect
Source citation (APA Format)	Rahmani, E., Dehestani, M., Beygi, M. H. A., Allahyari, H., & Nikbin, I. M. (2013). On the mechanical properties of concrete containing waste pet particles. *Construction and Building Materials*, *47*, 1302–1308. https://doi.org/10.1016/j.conbuildmat.2013.06.041
Original URL	https://www.sciencedirect.com/science/article/pii/S095006181300559X
Source type	Journal Article
Keywords	polyethylene Therephthalate (PET); concrete; physical and mechanical properties; ultrasonic test; waste management
#Tags	#concrete #plastic #pet #properties #recycling
Summary of key points + notes (include methodology)	PET is used to make many different plastic objects, notably plastic bottles, causing scientists to think of ways to recycle and reuse them to lessen their waste. One of these ways was through substituting various percentages of aggregate or mortar for PET processed particles in concrete. Tests on the concretes' properties concluded that although the tensile strength, stiffness and structure were harmed, many mechanical properties such as post-cracking behavior and toughness were recorded to have increased. Furthermore, PET reduced tensile strength and stiffness, which would be beneficial when ductility is needed. Additionally, it had a more porous structure, meaning that it was quieter.
Research Question/Problem/ Need	What are the effects of waste PET particles in concrete?
Important Figures	Figure 5

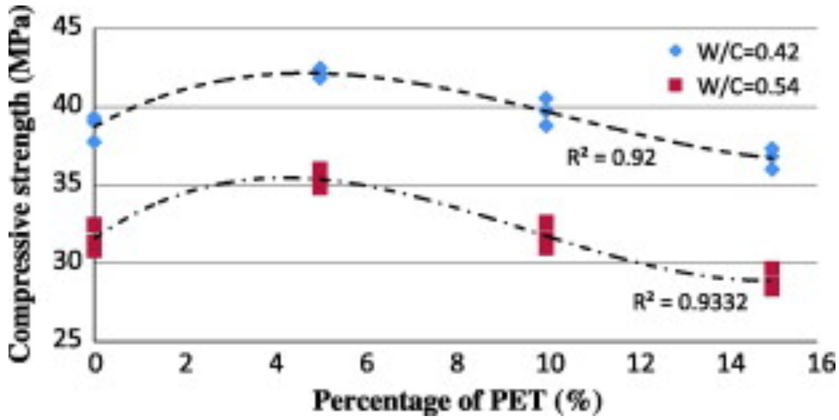
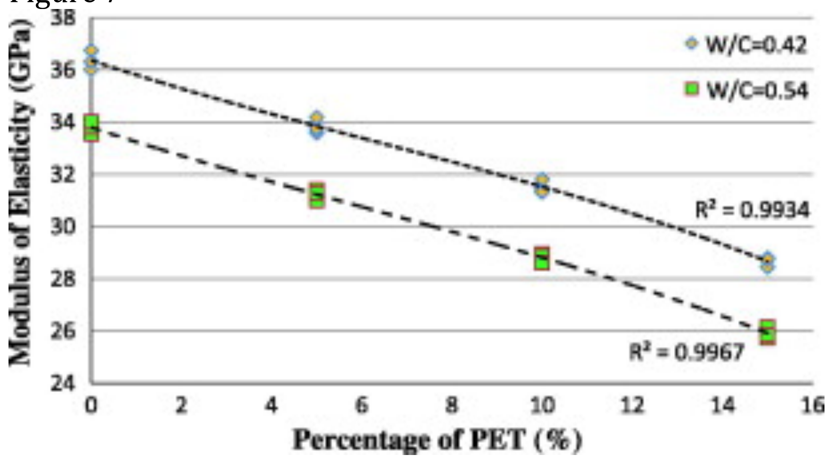


Figure 7



VOCAB: (w/definition)

Aggregate – granular, inert materials like sand, gravel, or crushed stones that provide strength, bulk, and structure to the concrete mix

Modulus – the absolute value of a real or complex number

Splitting Tensile Strength – the measure of a material's ability to withstand tensile stresses applied perpendicular to its surface, causing it to fracture

Brittle Failure – the sudden breaking of a material with little to no prior deformation, or plastic deformation

Grinding (Machining) – an abrasive machining process that utilizes high-speed abrasive wheels, pads, and belts to shape and finish materials

Abrasive – capable of polishing or cleaning a hard surface by rubbing or grinding

Cited references to follow

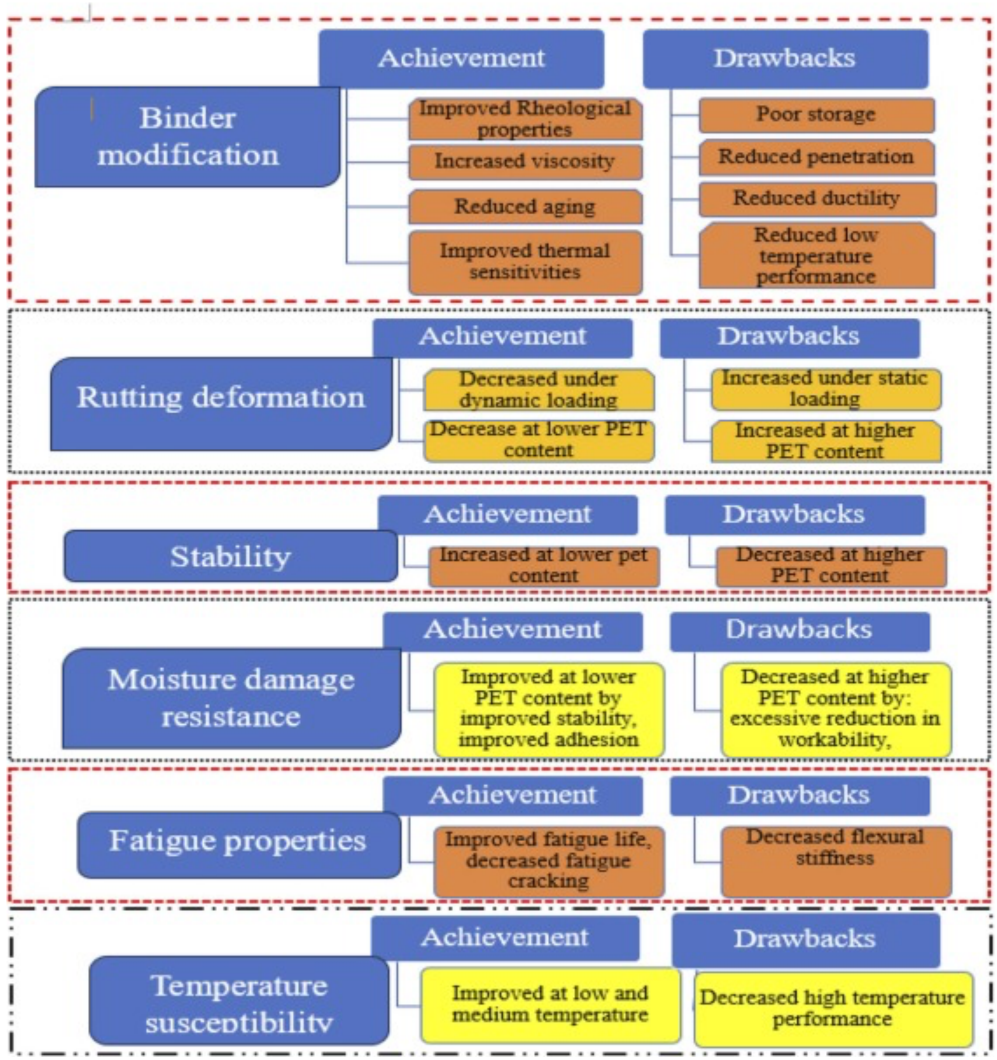
https://www.sciencedirect.com/science/article/pii/S0956053X090017

up on	67 https://www.sciencedirect.com/science/article/pii/S0958946509001668
Follow up Questions	• How does the results change when PET is new rather than being from waste bottles? • What would happen if the substitution procedure was based on weight rather than volume? • How well does concrete using PET hold up in a long-term scenario when compared to concrete without PET?

Article #2 Notes: Influence of Polyethylene Terephthalate (PET) utilization on the engineering properties of asphalt mixtures: A review

Source Title	ScienceDirect
Source citation (APA Format)	Usman, I. U., & Kunlin, M. (2024). Influence of polyethylene terephthalate (PET) utilization on the engineering properties of Asphalt Mixtures: A Review. *Construction and Building Materials*, *411*, 134439. https://doi.org/10.1016/j.conbuildmat.2023.134439
Original URL	https://www.sciencedirect.com/science/article/pii/S0950061823041582
Source type	Journal Article
Keywords	Plastics; Polyethylene Terephthalate (PET); Asphalt mixtures; PET-modified asphalt mixture; Rutting deformation; Moisture susceptibility
#Tags	#asphalt #pet #plastic #properties
Summary of key points + notes (include methodology)	PET accounts for about 60% of all plastics. This journal article compiles the findings of a multitude of studies focused on the effects on the mechanical properties of PET in different asphalt mixtures (binder and aggregate). The overall findings were that PET increases the stability, resistance to moisture susceptibility, rutting deformation, and fracture resistance. At the same time, though, it is referenced that certain studies indicate a decline in mechanical properties of asphalt when PET is a large percentage of the mixture. Waste PET is often used in dry process for adding it to asphalt mixtures, rather than wet processes. Asphalt has been shown to be a promising method to recycling PET, both as a binder modifier and as a part of the aggregate. Overall, studies indicate that low percentages of PET in asphalt at low to medium temperatures increase the mechanical properties of the mixture. Summarized methodology and findings for each study found in Zotero annotations. - Magenta: Sections - Red: Claims/conclusions of sections

	- Blue: Methodology - Purple: Findings of the studies - Orange: Introductions - Yellow: Background - Green: Figures/tables - Underline: specific studies
Research Question/Problem/ Need	What are the effects of PET in asphalt?; Is it a possible way to recycle PET?
Important Figures	Figure 1  Figure 22

	
VOCAB: (w/definition)	**Micronized** - break (a substance) into very fine particles. **Aminolysis** – "a chemically based functionalization method that introduces reactive amine groups on the surface of polymers through treatment with diamines, enhancing surface roughness and wettability while enabling the immobilization of biomolecules via conjugation reactions." - https://www.sciencedirect.com/topics/engineering/aminolysis **SMA** – "SMA, or Stone Mastic Asphalt, is defined as a gap-graded, densely compacted hot mix asphalt (HMA) used as a surface course, comprising asphalt cement, coarse aggregate, crushed sand, and additives, designed to enhance rut resistance and performance under heavy traffic conditions. It typically contains a higher proportion of coarse aggregate compared to standard dense-graded HMA, providing improved shear, abrasion, cracking, and skid resistance." -

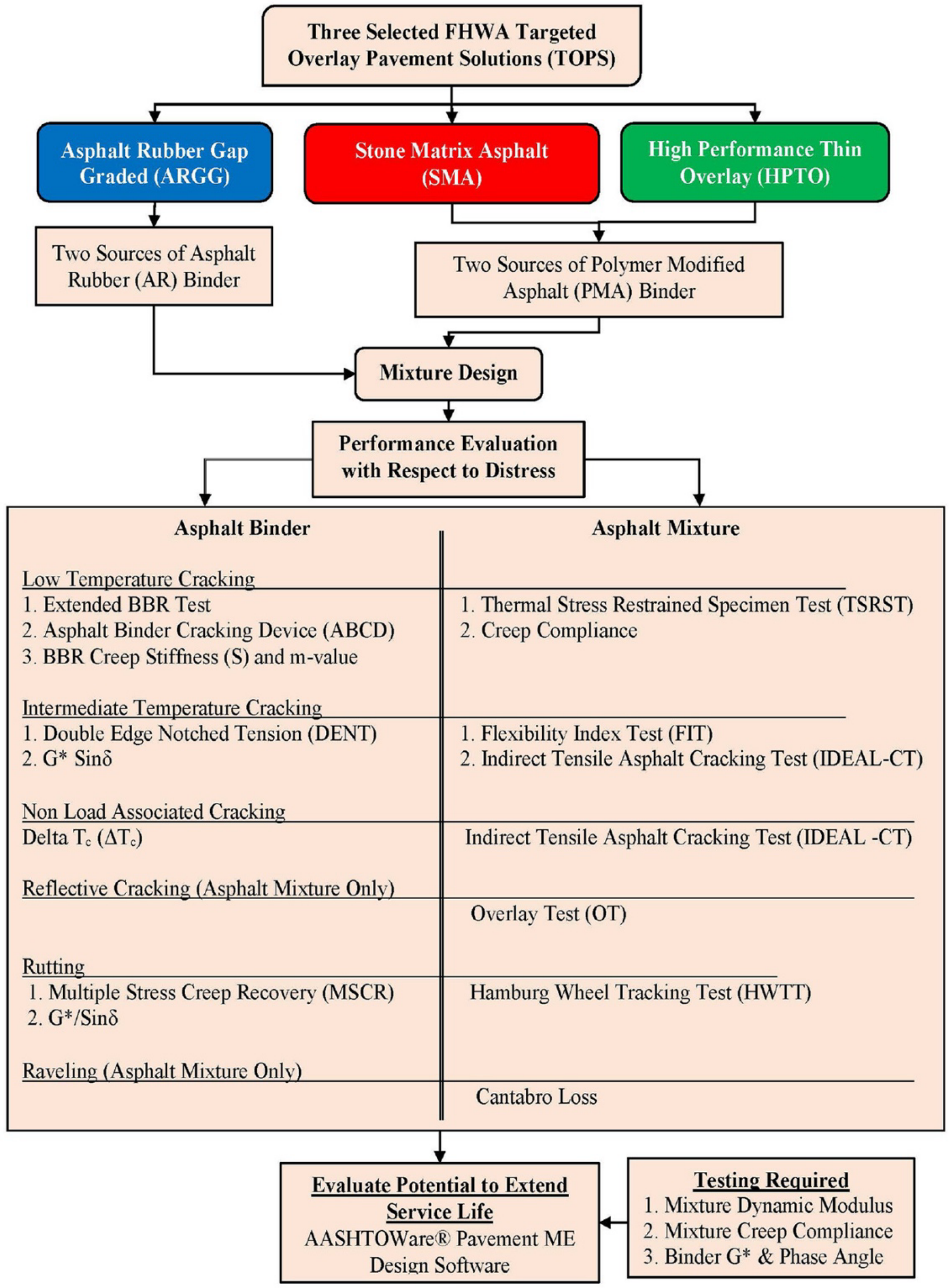
	https://www.sciencedirect.com/topics/materials-science/mastic-asphalt **Irradiated** - expose to radiation.
Cited references to follow up on	https://chemistry-europe.onlinelibrary.wiley.com/doi/abs/10.1002/cssc.202101631 https://www.mdpi.com/2313-4321/6/3/49 https://www.sciencedirect.com/science/article/pii/S0956053X17305354 https://www.tandfonline.com/doi/abs/10.1080/14680629.2019.1588776
Follow up Questions	- What is the dry process? - What if the PET is not uniform? - What is the optimal amount of PET? - Fibers vs particles?

Article #3 Notes: Evaluation of Three Federal Highway Administration Targeted Overlay Pavement Solutions for Asphalt Pavements Based on Their Performances and Potential to Increase Pavement Service Life

Article notes should be on separate sheets

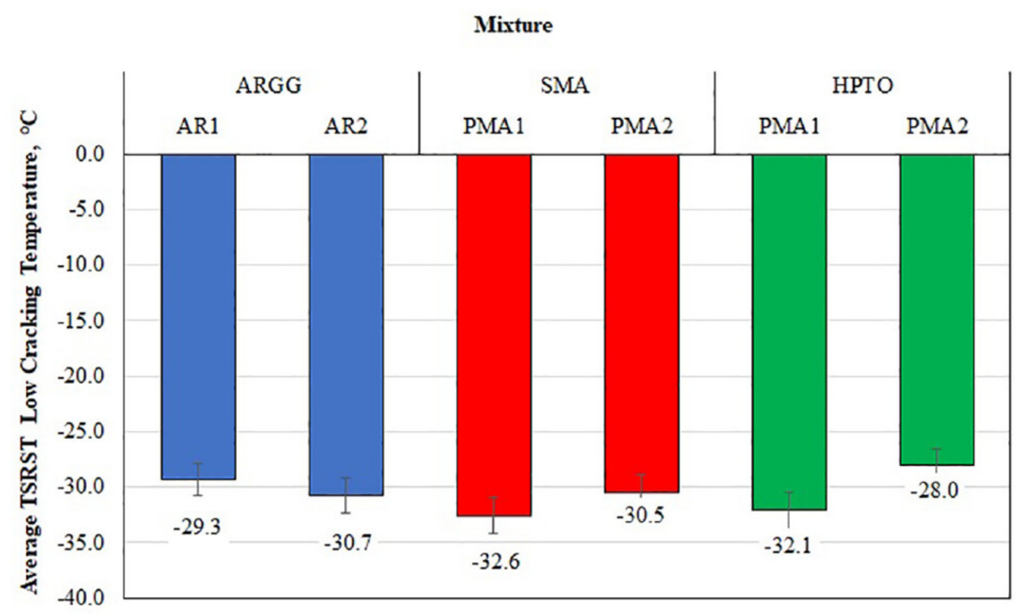
Source Title	Sage Pub
Source citation (APA Format)	Mogawer, W. S., Austerman, A. J., Abdalfattah, I. A., & Stuart, K. D. (2023). Evaluation of three Federal Highway Administration targeted overlay pavement solutions for asphalt pavements based on their performances and potential to increase pavement service life. *Transportation Research Record: Journal of the Transportation Research Board*, *2679*(1), 934–952. https://doi.org/10.1177/03611981231186421
Original URL	https://journals.sagepub.com/doi/full/10.1177/03611981231186421
Source type	Journal Article
Keywords	pavements, design and rehabilitation of asphalt pavements, asphalt, mechanistic-empirical pavement design, sustainable and resilient pavements, sustainable pavements
#Tags	#SMA #email
Summary of key points + notes (include methodology)	There are currently three proposed solutions for both asphalt and concrete pavements: Asphalt Rubber Gap-Graded (ARGG), Stone Mastic Asphalt (SMA), and High-Performance Thin Overlay (HPTO). They tested each of these Federal Highway Administration Targeted Pavement Solutions (TOPS) for performance, pavement service life, and whether they can be used interchangeably to see whether one is better than the rest. They also used two different asphalt binders in each of the TOPS types, providing six TOPS mixtures. ARGG uses a rubber-modified asphalt binder which incorporates approximately 20% ground tire rubber. SMA consists of a stable stone-on-stone coarse aggregate and a rich asphalt binder along with a stabilizing agent such as fibers, asphalt modifiers, or both. HPTO have been reported to improve cracking and rutting

	resistances and extend pavement life. To test this, they measured the rheological and performance characteristics of the asphalt binders, measured the performance characteristics of asphalt mixtures, and found the effect of the binder source on asphalt binder and the mixture performance. Lastly, they used predictive models to determine how the TOPS extend pavement service life. Methodology is summarized using figure 1. Overall, the data did not indicate that one of the three TOPS was better than the others.
Research Question/Problem/ Need	Which TOPS is the best for performance, pavement service life, and can they be used interchangeably?
Important Figures	Figure 1



Three Selected FHWA Targeted Overlay Pavement Solutions (TOPS)
Asphalt Rubber Gap Graded (ARGG)
Stone Matrix Asphalt (SMA)
High Performance Thin Overlay (HPTO)
Two Sources of Asphalt Rubber (AR) Binder
Two Sources of Polymer Modified Asphalt (PMA) Binder
Mixture Design
Performance Evaluation with Respect to Distress
Asphalt Binder
Asphalt Mixture
Low Temperature Cracking
1. Extended BBR Test
2. Asphalt Binder Cracking Device (ABCD)
3. BBR Creep Stiffness (S) and m-value
1. Thermal Stress Restrained Specimen Test (TSRST)
2. Creep Compliance
Intermediate Temperature Cracking
1. Double Edge Notched Tension (DENT)
2. G* Sinδ
1. Flexibility Index Test (FIT)
2. Indirect Tensile Asphalt Cracking Test (IDEAL-CT)
Non Load Associated Cracking
Delta T_c (ΔT_c)
Indirect Tensile Asphalt Cracking Test (IDEAL -CT)
Reflective Cracking (Asphalt Mixture Only)
Overlay Test (OT)
Rutting
1. Multiple Stress Creep Recovery (MSCR)
2. G*/Sinδ
Hamburg Wheel Tracking Test (HWTT)
Raveling (Asphalt Mixture Only)
Cantabro Loss
Evaluate Potential to Extend Service Life
AASHTOWare® Pavement ME Design Software
Testing Required
1. Mixture Dynamic Modulus
2. Mixture Creep Compliance
3. Binder G* & Phase Angle

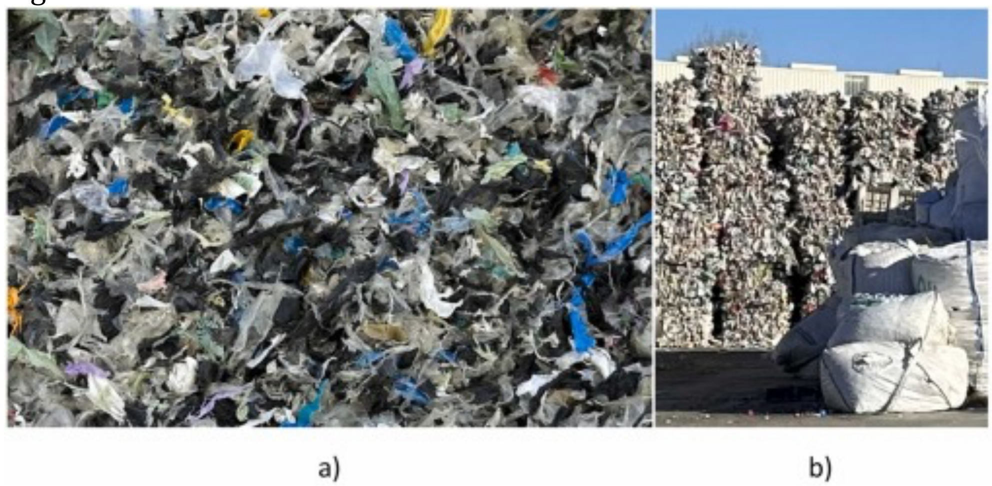
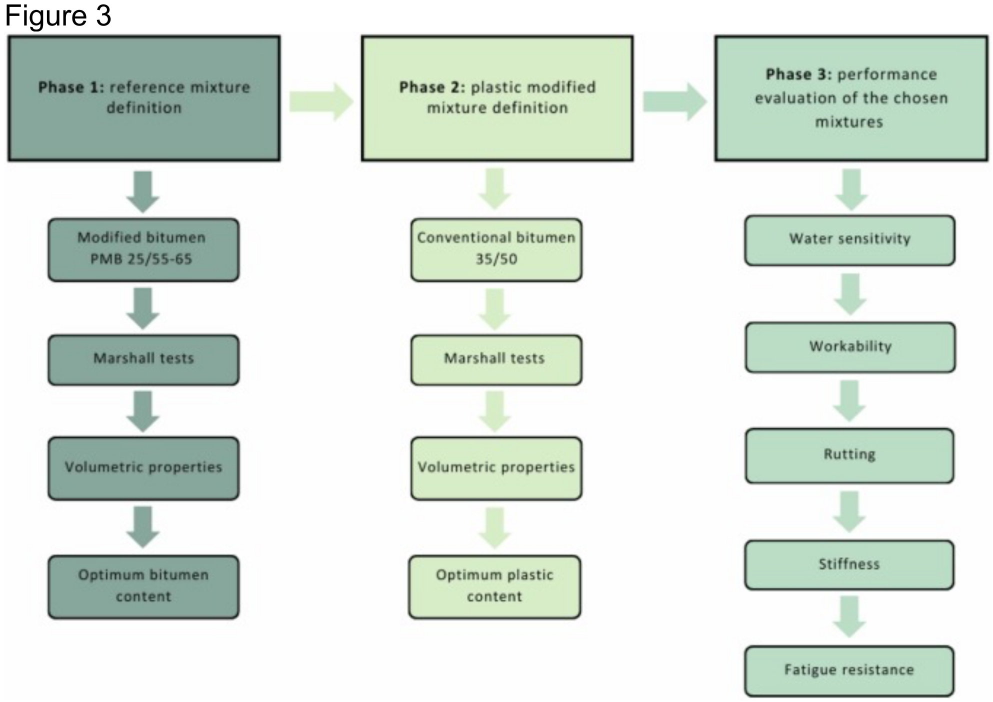
Figure 2

	
VOCAB: (w/definition)	**Rheological** - the study of how materials deform and flow under stress or strain **Creep** - the time-dependent, gradual deformation of a material under constant load or stress **Cellulose Stabilizing Fiber** - A natural or processed cellulose fiber added to asphalt mixtures **Pilot** - refers to a small-scale test or preliminary trial before full-scale implementation. **m-value** - The slope of the logarithmic creep compliance curve with respect to the logarithm of time, obtained from Bending Beam Rheometer (BBR) tests.
Cited references to follow up on	FHWA Office of Preconstruction, Construction, and Pavements. Stone Matrix Asphalt. FHWA-HIF-21-004. US Department of Transportation, Washington, D.C., n.d. https://www.fhwa.dot.gov/pavement/tops/pubs/asphalt_ tops_combined_508_4.pdf. Accessed February 3, 2023. Texas A&M Transportation Institute. IDEAL-CT — Simple, Reliable, Efficient, Repeatable, Cost Effective. Texas Transportation Researcher, Vol. 57, No. 1. https://tti.tamu. edu/researcher/ideal-ct-simple-reliable-efficient-repeatablecost-effective/. Accessed February 28, 2023.
Follow up Questions	- How does the compressive strength compare between TOPS? - What do the error bars indicate?

Article #4 Notes: Incorporation of plastic waste into road pavements: Performance of SMA mixtures containing flakes of low-density polyethylene

Article notes should be on separate sheets

Source Title	ScienceDirect
Source citation (APA Format)	Cardoso, J., Almeida, A., Santos, J., & Ferreira, A. (2025). Incorporation of plastic waste into road pavements: Performance of SMA mixtures containing flakes of low-density polyethylene. *Construction and Building Materials*, *471*, 140766. https://doi.org/10.1016/j.conbuildmat.2025.140766
Original URL	https://www.sciencedirect.com/science/article/pii/S0950061825009146?fr=RR-1&ref=cra_js_challenge
Source type	Journal Article
Keywords	Plastic waste; SMA mixtures; Fatigue cracking; Rutting; Mechanistic-empirical design
#Tags	#plastic #SMA #rutting #fatigue
Summary of key points + notes (include methodology)	They incorporated flakes of low-density polyethylene (LDPE) plastic waste into stone mastic asphalt mixtures with conventional bitumen instead of the usual polymer-modified bitumen. They tested for volumetric and Marshall properties, as well as water sensitivity, workability, rutting resistance, stiffness, and fatigue resistance. They also evaluated the structure using mechanistic-empirical analysis. LDPE are waste plastics, they used the Marshall mix design, and they made two mixtures: a control and the LDPE one. They aimed for it to hold up against the normal one, not necessarily do better. This resulted in them finding that the mixture showed excellent rutting resistance, a slight reduction in fatigue performance, and no major problems with the other properties. When modelling the structural behavior, it had better structural responses, indicating a longer life or reduced maintenance.
Research	Can waste LDPE flakes be incorporated into SMA mixtures using

Question/Problem/ Need	conventional bitumen.
Important Figures	Figure 3  Figure 3 
VOCAB: (w/definition)	**Low-Density Polyethylene (LDPE) –** a thermoplastic used in packaging, a waste plastic **Stiffness modulus –** a measure of how much a material resists deformation **Marshall properties –** results from the Marshall stability test, used to assess strength and durability
Cited references to follow up on	https://www.mdpi.com/1996-1944/13/7/1495 https://www.tandfonline.com/doi/full/10.1080/14680629.2019.1588779#d1e460

Follow up Questions	What is the best amount of LDPE? How does it effect the environment? Since flakes are different sizes, is it different between batches?

Article #5 Notes: Risky Giant Steps Can Solve Optimization Problems Faster. (Summer Article #1)

Source Title	Quanta Magazine
Source citation (APA Format)	Parshall, A. (2023, August 11). *Risky Giant Steps Can Solve Optimization Problems Faster*. Quanta Magazine. https://www.quantamagazine.org/risky-giant-steps-can-solve-optimization-problems-faster-20230811/
Original URL	https://www.quantamagazine.org/risky-giant-steps-can-solve-optimization-problems-faster-20230811/
Source type	Magazine
Keywords	optimization; gradient descent;
#Tags	#Summer
Summary of key points + notes (include methodology)	Allison Parshall writes about an optimization algorithm called gradient descent. Gradient descent uses a cost function where the height represents the cost – this could be the cost of time, energy, or malfunctions. The higher the point is, the greater the cost and thus, the less optimal it is. The goal of gradient descent is to find the lowest point of the function where the price is the smallest. It figures this out by calculating the slope of the curve around a point and then moving in the direction where the slope is steepest. From there, they take steps of lengths decided by the researcher. Giant leaps are riskier but can shave down time, while smaller steps have been safer. For decades, the consensus was to take steps no bigger than 2, even though no one could prove that this was always better. In 2022, MIT researcher Das Gupta, with the help of others, found that restricting an algorithm to only 50 steps to find the best step lengths led to the most optimal varying significantly in length. One step in the middle of the sequence nearly reached a length of 37. Using these findings, Grimmer, another researcher, found out in 2023 that the fastest sequences always had the middle step as the biggest one. The size of this middle step depended on the total number of steps in the sequence, with more steps generally meaning a larger leap in length for this middle step. On top of this, the pattern of the step sizes was all very symmetrical. This optimization proved to be significantly faster than taking "baby" steps, being nearly

	three times as fast. The one problem with this is that Grimmer focused only on smooth functions, which have no sharp turns and concavities. This means that his findings are fundamental to theory, but not as relevant in practice as optimization machine learning programs are not that simple. As such, these insights will not change how gradient descent is currently used as of right now. Even still, the repetition suggests a structure and strategy for the best solutions that no one has figured out yet.
Research Question/Problem/ Need	Is there a better way to do gradient descent on a straight line?
Important Figures	n/a – no figures
VOCAB: (w/definition)	**Gradient Descent** - an iterative optimization algorithm that finds the minimum of a function by repeatedly moving in the direction of the steepest descent, which is the opposite of the gradient **Cyclical** - occurring in cycles; recurrent.
Cited references to follow up on	https://link.springer.com/article/10.1007/s10107-023-01973-1
Follow up Questions	How would this change for concave models?

Article #6 Notes: Bird-inspired reflexive morphing enables rudderless flight (Summer Article #2)

Article notes should be on separate sheets

Source Title	Science Robotics
Source citation (APA Format)	Chang, E., Chin, D. D., & Lentink, D. (2024). Bird-inspired reflexive morphing enables rudderless flight. *Science Robotics*, *9*(96). https://doi.org/10.1126/scirobotics.ado4535
Original URL	https://www.science.org/doi/10.1126/scirobotics.ado4535
Source type	Journal Article
Keywords	Birds; Wings; Robotics; Flight; Rudder-less
#Tags	#Summer
Summary of key points + notes (include methodology)	Birds can glide without rudders by morphing the shapes of their wings and tails continuously, unlike a plane. A plane generally needs a rudder, which angles the aircraft in the right way, being more efficient than using differential drag. On the other hand, if a rudder is incorrectly sized or removed, the plane will experience Dutch roll instability. As such, most planes use a rudder, but in rare cases, some use split flaps, differential spoilers, or have specially tuned wing geometries. But birds can fly without a "rudder" or something similar while also being more efficient and flexible. Although many robots have been designed based on birds, they have not been able to sustain flight. To enable flight, scientists think that birds rely on reflexes that constantly adapt to the changing weather conditions while flying. In this publication, Eric Chang, Diana D. Chin, and David Lentink decided to test this theory as well as create a robot that can accomplish the same thing. This robot had real pigeon feathers arranged in a biomimetic skeleton to form wings and a tail, allowing them to mimic the bird's instinctive movements during flight. This was done by considering the way that pigeons adjust their wings and tails to maintain stability and using a PID control loop to tune the robot's responses to the changes in wind or weather. This reflexive morphing helped stabilize flight, preventing Dutch rolls and improving control during actions such as takeoff and landing. In the beginning, it was evidently shown that having only the tail morph was not enough to counteract Dutch rolls and stabilize the robot during flight, but when they added morphing wings, the robot

	stabilized. Then, they did outdoor flight tests, confirming that the robot could stay stabilized even though it did not have a rudder or vertical tail. They also found that some configurations, such as the tucked-wing combined with the tucked-tail, led to problems such as excessive descent rates. This is important because it hints at improved maneuverability, reduced radar signature, and increased efficiency in aircraft without rudders or vertical tails.
Research Question/Problem/ Need	How do birds fly without a vertical tail, and how can that be used to make a robot do the same?
Important Figures	Figure 1

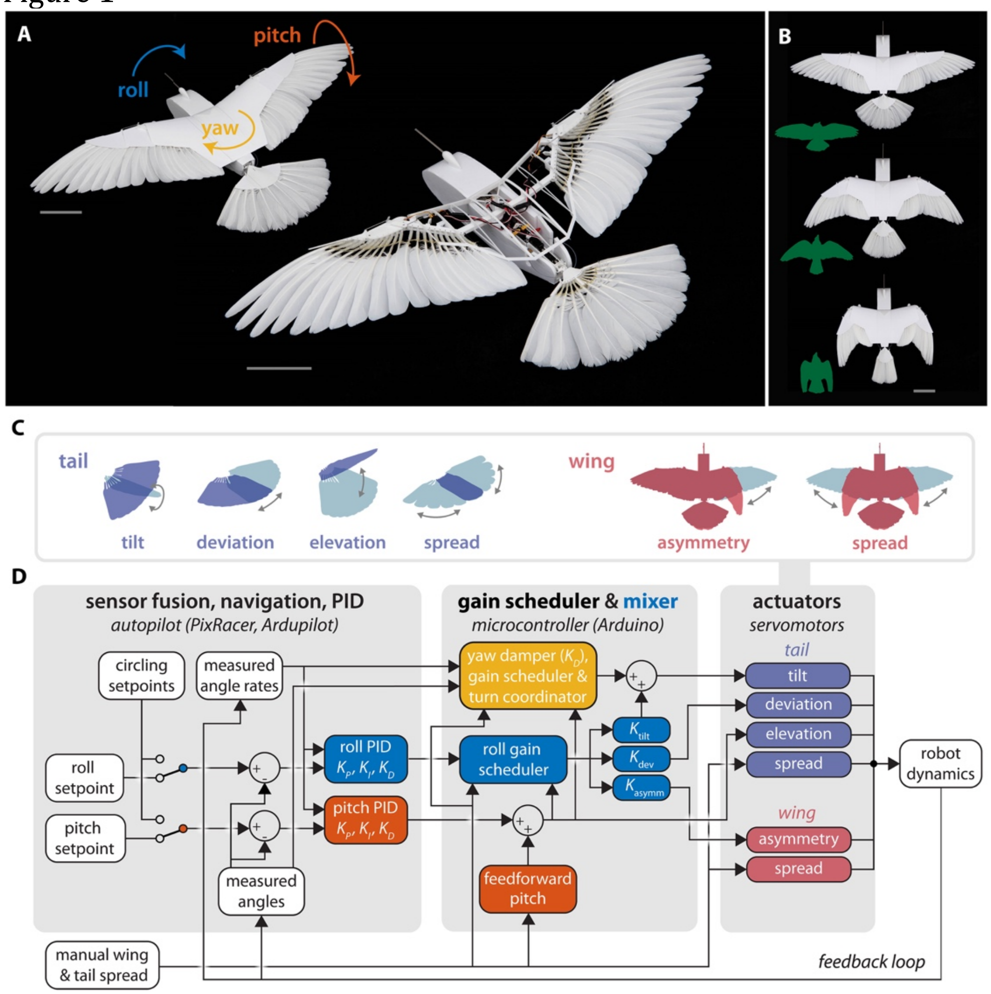
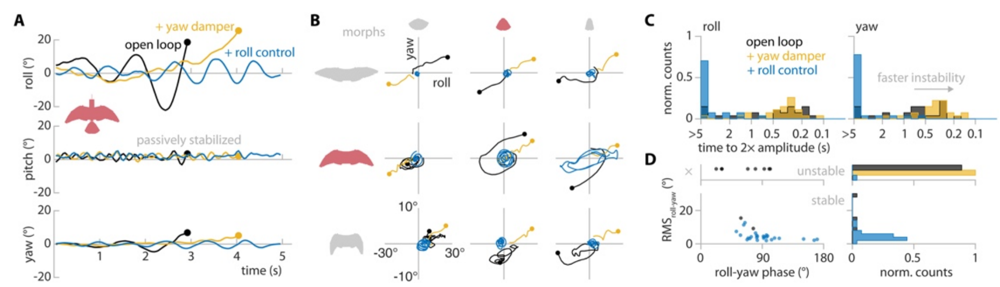


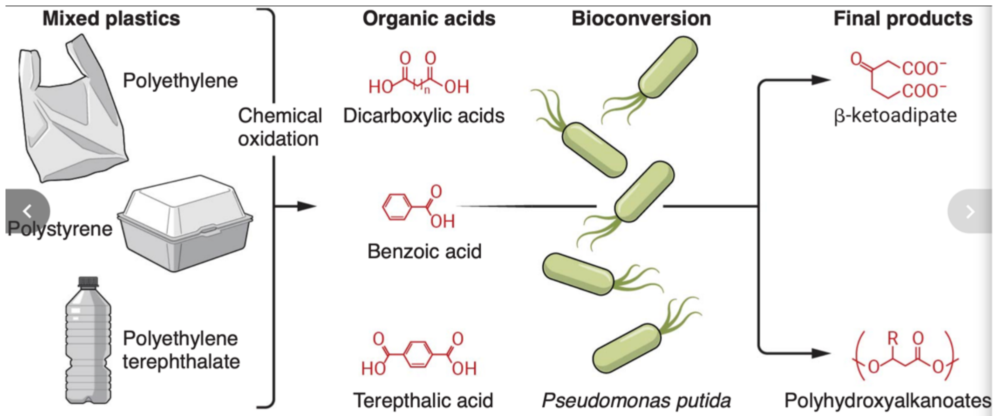
Figure 2

	
VOCAB: (w/definition)	Dutch roll **Rudder-less** - Describes an object (like a bird or aircraft) that cannot actively steer or change direction because it lacks a rudder or similar control mechanism. **Autonomous** - Acting independently or self-directed; able to operate without outside control. **Mechanosensory** - Relating to the detection of mechanical stimuli such as touch, pressure, vibration, or movement. **Filoplumes** - A type of small, hair-like feather found near contour feathers on birds. **Ailerons** - Hinged control surfaces located on the trailing edge of airplane wings used to roll planes. **Weathercock Stability** - The tendency of an object (like a weather vane or an airplane) to align itself with the wind or airflow.
Cited references to follow up on	https://www.jstage.jst.go.jp/article/tjsass/66/3/66_T-22-36/_article/-char/ja/ https://d1wqtxts1xzle7.cloudfront.net/60466651/Flight_Stability_and_Automatic_Control20190902-80669-149kism-libre.pdf?1567455888=&response-content-disposition=inline%3B+filename%3DFlight_Stability_and_Automatic_Control.pdf&Expires=1759619170&Signature=QwMWVaD-6ihfby4FCer3M7Zoo7gQu3gJoXkZ0cq7MNOoThIHjiD0iXnVNjhoopm0F0jtpe6d6w2PRt~DqL9saeLXdKE6fWBR~uasGyOudqoQsDbHbXD2e013T2Unbxi3~lJsuyV7JZi3hgEDiRN6Ay6vKJBJgnDOK~oiMt69wKjA0Nxx-tsZzykLuhrEHwiU~HfIOYTLsFu9RAgY5CKa2O-cq7StTbZBgFyxmpFNp-OzjP2TkSTmLYG0z4gX~J0fa6Pt-tWD0tSiTpovAh2XT4LLPiydLyNmZy2lKv8Yk-V3oTzFYctQyBdRx0waUH~lJgGBiqTQ2IVCH2htUqEf9A__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA
Follow up Questions	How can this be implemented into larger models? How can this be used?

Article #7 Notes: Recycling plastic using a hybrid process (Summer Article #3)

Article notes should be on separate sheets

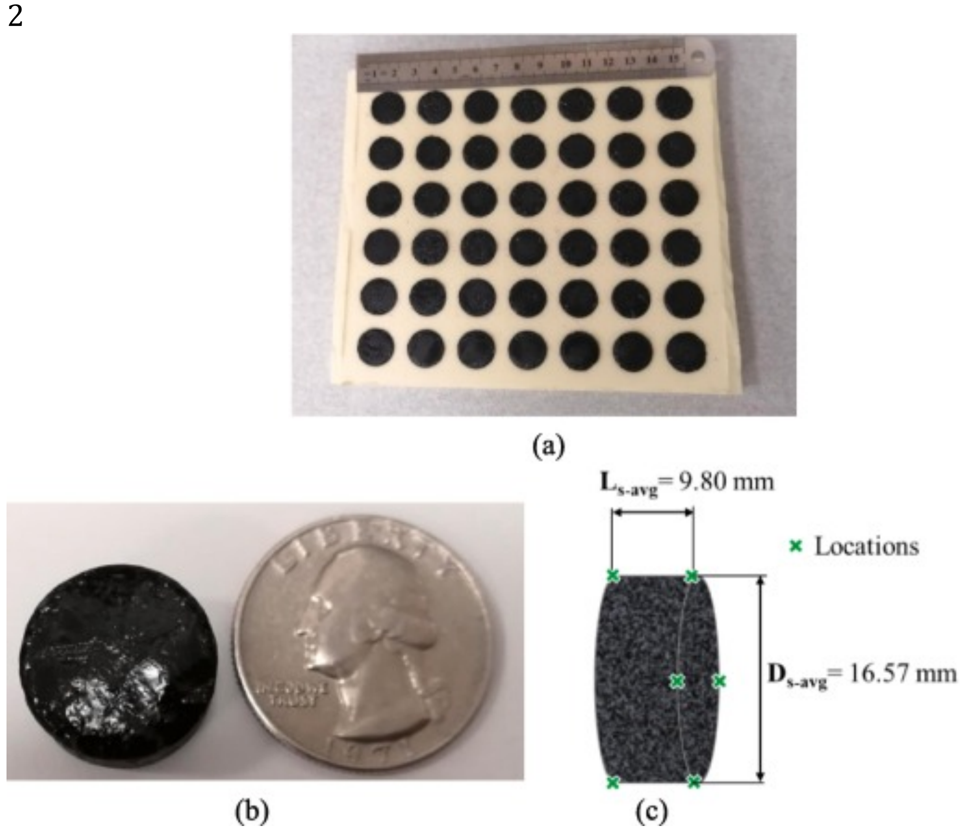
Source Title	Science Org
Source citation (APA Format)	Yan, N. (2022, October 13). *Recycling plastic using a hybrid process*. https://www.science.org/doi/10.1126/science.ade5658
Original URL	https://www.science.org/doi/10.1126/science.ade5658
Source type	Magazine
Keywords	Plastic; Recycling; PET; Hybrid
#Tags	#Recycling #Plastic #PET
Summary of key points + notes (include methodology)	Plastic recycling is traditionally carried out using mechanical methods, which often degrade the material's quality and result in down-cycling. Recently, scientists have developed chemical processes that break plastics down into their original monomers in order to reuse them, but these methods typically work only for specific types of plastics. Sullivan and his colleagues have reported a hybrid two-step approach capable of handling plastic mixtures. First, the plastic mixture is broken down into organic acid intermediates. Then, these intermediates are biologically converted into oxygenated compounds using specialized bacteria. This process works on multiple types of plastics and can produce performance-enhanced polymers. Plastics are notoriously difficult to break down due to their stable polymer structures and low oxygen content. To address this, oxidation treatments are used to boost oxygen levels, making them more susceptible to degradation. By combining chemical and biological processing, this hybrid method enables forms of plastic recycling that were previously considered impractical.
Research Question/Problem/ Need	How can mixed plastic waste (such as polystyrene, polyethylene, and PET) be efficiently converted into useful, valuable chemical products through a combined chemical and biological process?

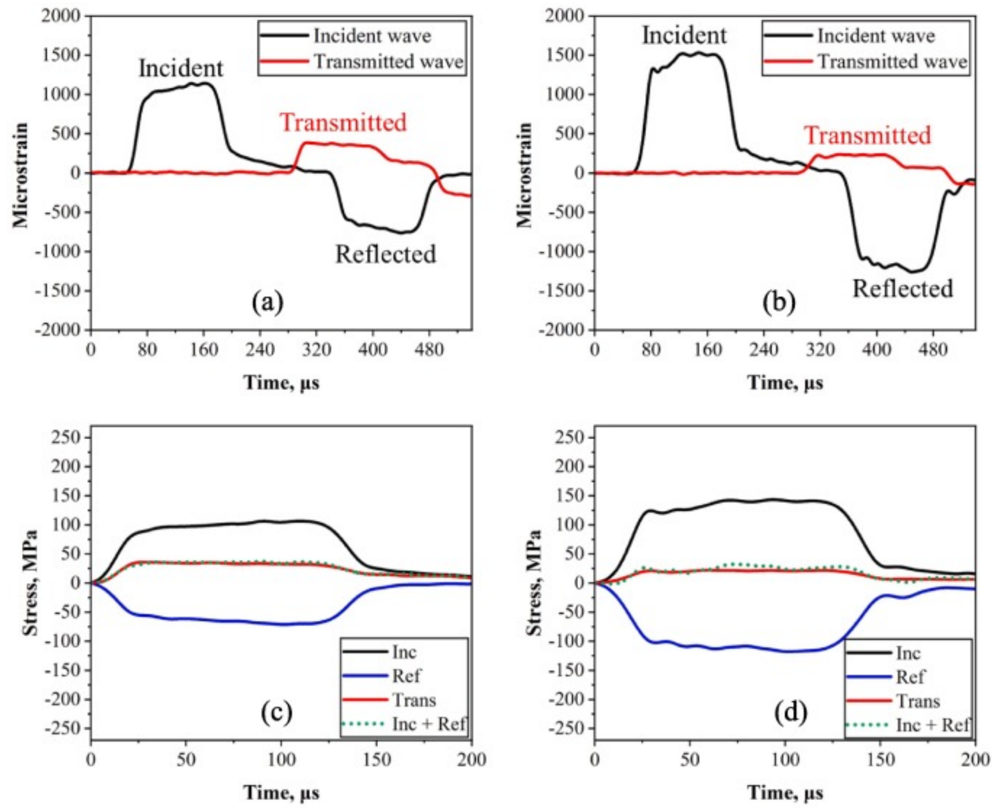
Important Figures	
VOCAB: (w/definition)	**Polystrene (PS)** - A lightweight plastic used in foam packaging and insulation (e.g., Styrofoam). It's brittle and not biodegradable **Chemical Oxidation** - A process that uses oxidizing agents to break down large organic molecules (like plastics) into smaller, oxygen-rich compounds **Biological Conversion** - Using living organisms to transform chemical substances into new, useful products **Polyhydroxyalkanoates (PHAs)** - A class of biodegradable plastics naturally made by some bacteria. They are potential eco-friendly alternatives to petroleum-based plastics **Oxygenation** – Adding oxygen atoms to molecules
Cited references to follow up on	https://pubmed.ncbi.nlm.nih.gov/33093105/ https://pubmed.ncbi.nlm.nih.gov/33269513/
Follow up Questions	What are the limitations? How could it be more energy-efficient? Can different bacteria be used?

Article #8 Notes: Aging and temperature effects on the dynamic characteristics of asphalt mortar under impact loading

Article notes should be on separate sheets

Source Title	ScienceDirect
Source citation (APA Format)	Diouri, K., El-Korchi, T., Karanjgaokar, N., & Mallick, R. B. (2023). Aging and temperature effects on the dynamic characteristics of asphalt mortar under impact loading. *Construction and Building Materials*, *369*, 130572. https://doi.org/10.1016/j.conbuildmat.2023.130572
Original URL	https://www.sciencedirect.com/science/article/pii/S0950061823002830
Source type	Journal Article
Keywords	Impact loading; Milling; Split Hopkinson Pressure Bar; Asphalt mortar; Long-term oven aging; Dynamic fragmentation
#Tags	#Asphalt #Asphalt mortar #email #Impact loading #Aging
Summary of key points + notes (include methodology)	The researchers investigated the behavior of asphalt mortar under high strain rates. They also analyzed the effects of temperature and long-term oven aging (which is a laboratory process that simulates the effects of heat and oxygen exposure on real pavement). They used PG 64-28, which is one of the most common asphalt binders in the New England region. It was modified with Polyphosphoric acid (PPA). They used 3D printing to make inverse molds using silicone. They then mixed all the materials together and then put them into the molds. Afterwards, they made 24 samples that were unaged, aged for 24 hours, and aged for 72 hours at 85 ºC. They tested for asphalt milling rates to study temperature and aging effects. Afterwards, they implemented the split Hopkinson pressure bar (SHPB) system. With the data collected from the SHPB system they did Fourier Transform Spectroscopy (FTIR) to analyze the data. From this they found that the 24-hour and 72-hour

	samples equated to the 4-19 years of field aging, validating that oven aging simulated long-term service. They also found that the aging process decreases dynamic strength and that there was failure through aggregates at higher strain rates. Furthermore, they found that there was a slight strength increase and strong relationship between temperature and strain rate. Additionally, aging did not change stiffness significantly and that higher temperatures made the test materials more ductile. They found that the failure can be shown through four different ways, visible cracks only, edge fracturing, splitting, and pulverization. On top of these four ways, they found that low temperature and high strain rate created severe fragmentation, and high temperature created larger and fewer fragments.
Research Question/Problem/ Need	How do temperature and long-term oven aging affect the dynamic mechanical behavior and failure characteristics of asphalt mortar under impact loading conditions?
Important Figures	Figure 2  Figure 6



VOCAB: (w/definition)	**Oven aging** – laboratory procedure to simulate long-term field aging by heating asphalt materials **Oxidation** – chemical reaction with oxygen that makes asphalt stiffer and more brittle over time **Fourier Transform Infrared Spectroscopy (FTIR)** – a technique that identifies chemical bonds and functional groups in a material by how they absorb infrared light
Cited references to follow up on	https://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP09-54_InterimReport-Submitted10-25-13.pdf https://dl.astm.org/acem/article-abstract/8/1/527/540/Effect-of-Long-Term-Aging-on-Fracture-Properties?redirectedFrom=fulltext
Follow up Questions	How did they produce small batches? How accurate is oven aging? How does FTIR work?

Article #9 Notes: Utilization of waste fibers in stone matrix asphalt mixtures

Article notes should be on separate sheets

KEEP THIS BLANK AND USE AS A TEMPLATE

Source Title	ScienceDirect
Source citation (APA Format)	Putman, B. J., & Amirkhanian, S. N. (2004). Utilization of waste fibers in stone matrix asphalt mixtures. *Resources, Conservation and Recycling*, *42*(3), 265–274. https://doi.org/10.1016/j.resconrec.2004.04.005
Original URL	https://www.sciencedirect.com/science/article/pii/S0921344904000643
Source type	Journal Article
Keywords	Asphalt; Stone matrix asphalt; Stone mastic asphalt; Fibers; Scrap tires; Waste materials; Carpet waste
#Tags	#SMA #asphalt #recycling
Summary of key points + notes (include methodology)	In this study they used PG 76-22 polymer-modified asphalt binder, crushed granite for the aggregate, and hydrated limestone for the mineral filler. They tested the fibers cellulose (which is the control), polyester, scrap tire fibers between 3 and 13 mm, and waste carpet fibers. The fiber was 0.3% of the total weight, and asphalt content varied to find the optimum asphalt content. They tested for drain down at 162 and 177 ºC with comparisons to those without fibers. They also tested for moisture susceptibility by measuring the indirect tensile strength (ITS) of wet and dry samples, which they used to calculate the tensile strength ratio (TSR) and toughness. Furthermore, they measured rut depth and dynamic stability using an asphalt pavement analyzer at 76 ºC. They found that waste tire and carpet fibers can serve as effective and sustainable stabilizing additives in SMA, matching or exceeding the performance of commercial cellulose and polyester while also offering economic and environmental advantages.

<table>
<tr><td>Research Question/Problem/ Need</td><td>What is the feasibility of utilizing waste tire and carpet fibers in SMA?</td></tr>
<tr><td>Important Figures</td><td>
Figure 1

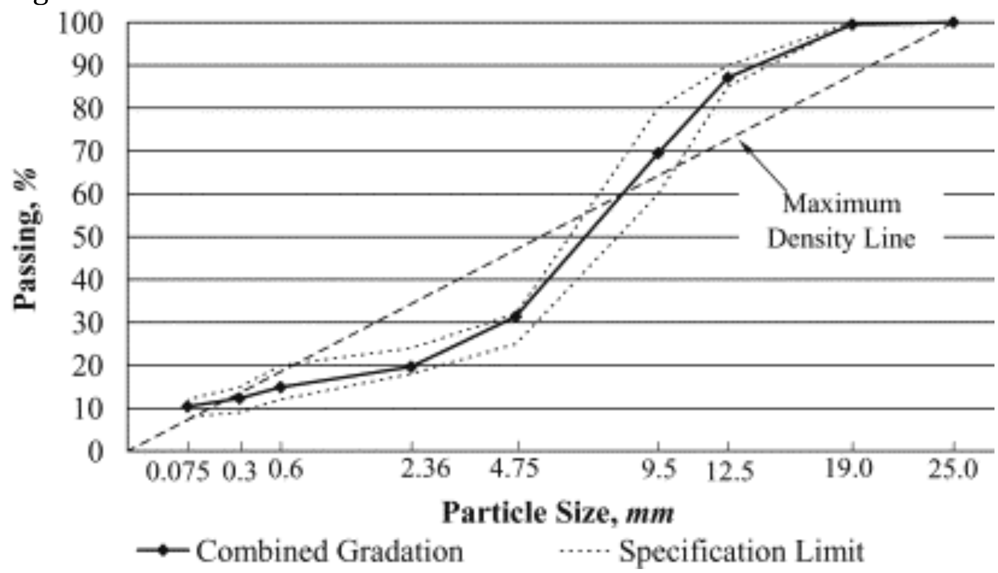
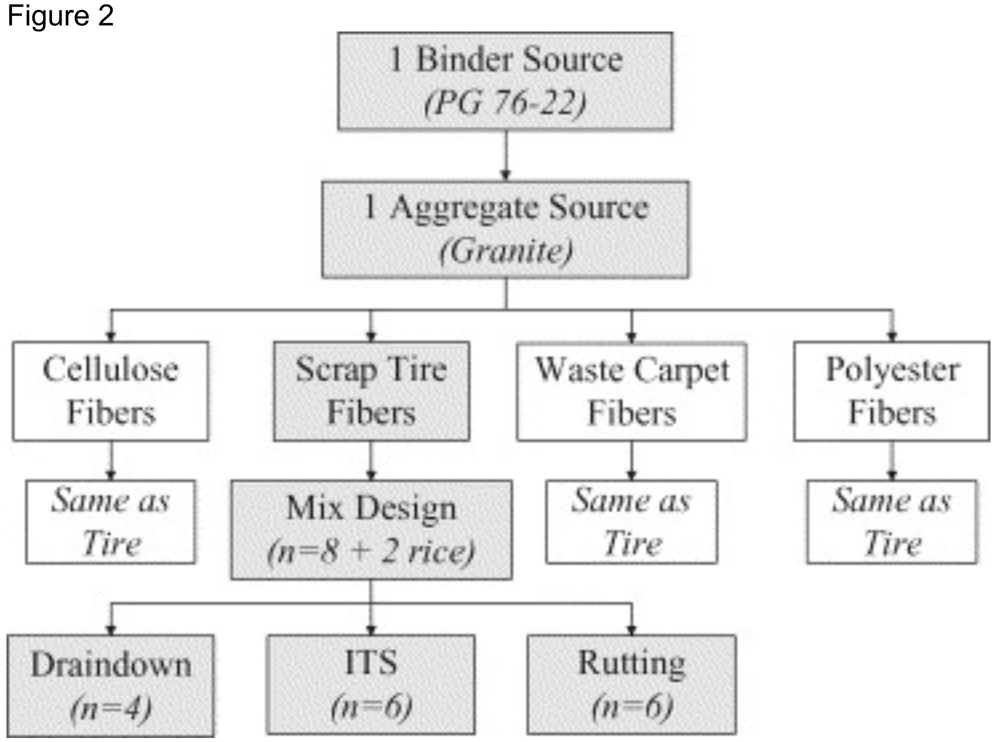


Figure 2



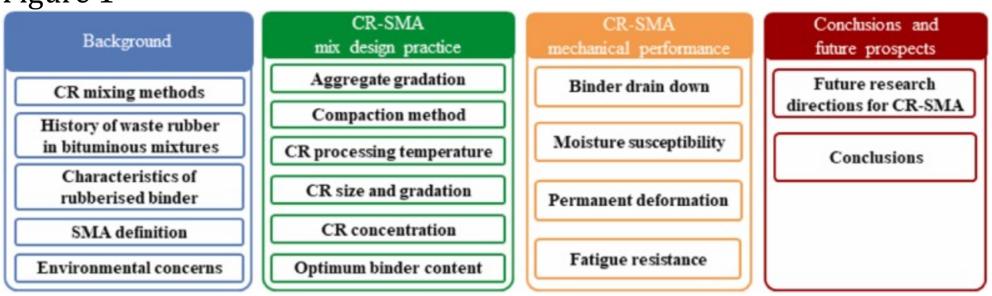
</td></tr>
<tr><td>VOCAB: (w/definition)</td><td>Optimum Asphalt Content (OAC) – the binder percentage that gives the mix the best balance of strength, durability, and air voids
Fiber stabilizer – materials added to SMA to prevent drain down and increase toughness
Drain down – the leakage or drainage of asphalt binder from the mix at</td></tr>
</table>

	high temperatures **Hydrated lime** – a mineral filler and anti-strip additive that improves bonding between asphalt and aggregate and reducing moisture damage
Cited references to follow up on	https://rosap.ntl.bts.gov/view/dot/13192 https://onlinepubs.trb.org/onlinepubs/millennium/00079.pdf
Follow up Questions	Why is 0.3% fiber content used, and what if it is different? How does fiber shape influence it?

Article #10 Notes: The use of waste tyre rubber in Stone Mastic Asphalt mixtures: A critical review

Article notes should be on separate sheets

Source Title	ScienceDirect
Source citation (APA Format)	Zakerzadeh, M., Shahbodagh, B., Ng, J., & Khalili, N. (2024). The use of waste tyre rubber in stone mastic asphalt mixtures: A critical review. *Construction and Building Materials*, *418*, 135420. https://doi.org/10.1016/j.conbuildmat.2024.135420
Original URL	https://www.sciencedirect.com/science/article/pii/S0950061824005610
Source type	Journal Article
Keywords	Recycled tire rubber; Stone Mastic Asphalt (SMA); Sustainable pavement; Mix design; Crumb Rubber (CR)
#Tags	#SMA #Recycling #asphalt
Summary of key points + notes (include methodology)	In this study, they evaluate the mix design practices of Crumb Rubber-Stone Mastic Asphalt (CR-SMA) mixtures. They assessed the performance characteristics and identified gaps and potential areas for improvement. CR provides a multitude of benefits including: the mitigation of reflection cracking, improved resistance to fatigue cracking and rutting, reduced maintenance and rehabilitation intervals, prolonged pavement service life, and decreased tire/pavement noise levels. There are two methods of mixing CR into the mixtures. The wet process replaces some of the bitumen, which improves viscosity, toughness, and stiffness. It also needs higher production costs, high energy consumption and high ambient temperature, as well as the need for specialized mixing equipment and it being less stable to store. On the other hand, there is the dry method with involves blending CR particles with the aggregate before it is mixed with the bitumen, allowing it to substitute for the fine aggregates. The problem with this is that is leads to not enough interaction between the bitumen and CR. As such, it is more susceptible to moisture and needs to determine the new best

	amount of binder content. Crumb rubber is generally shredded and grinded into particles using large machinery like cracker mills, granulators, micro-mills, and cryogenic equipment. There are two specific methods: ambient and cryogenic. The ambient processing method involves grinding waste tires at or above room temperature using mechanical blades, resulting in irregularly shaped particles with torn edges and a spongy surface. The cryogenic method involves freezing the waste rubber using liquid nitrogen to achieve brittleness. They then would grind it using hammer mills to produce the grains. It was found that rubber particles made from the ambient method had a larger surface area, lower density, rougher texture, and more porous nature, as well as being more cost effective. There is also a third method that is used much less due to its need for specific equipment and high energy consumption, although it does make high-quality reclaimed rubber. Overall, the performance of the mixture depends on the interactions between the CR particles and bitumen. In SMA, the mixtures generally contain 70-80% coarse aggregate, 8-12% filler, 6-7.5% bitumen (possibly polymer modified), as well as 0.3-0.4% cellulose or mineral fibers to the mix in order to prevent binder drain-down. From this evaluation, they found that incorporating CR into SMA improves sustainability, reduces costs, and enhances mechanical performance. Furthermore, CR can replace fibers and polymers in SMA, reducing drain-down and improving strength, although aggregate gradation must be adjusted to account for the CR particles. Additionally, CR-SMA has a similar moisture resistance to regular SMA, and it is indicated that warm-mix asphalt (WMA) additives may reduce moisture resistance. There is future work needed to optimize rubber treatment, mix design, and temperature control as well as figuring out the balance between sustainability with performance and durability.
Research Question/Problem/ Need	How does the CR influence the mechanical performance, production process, and sustainability of SMA mixtures?
Important Figures	Figure 1  Figure 2

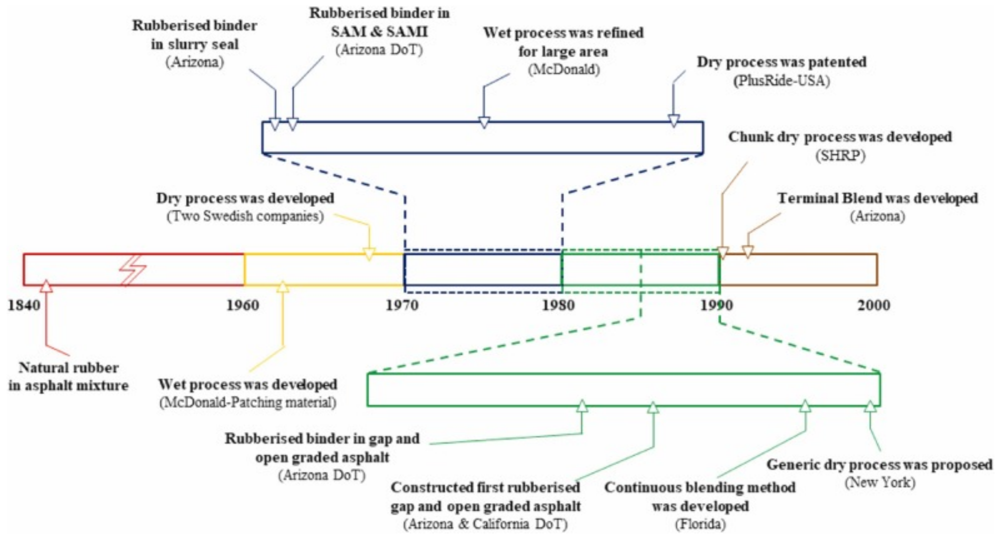
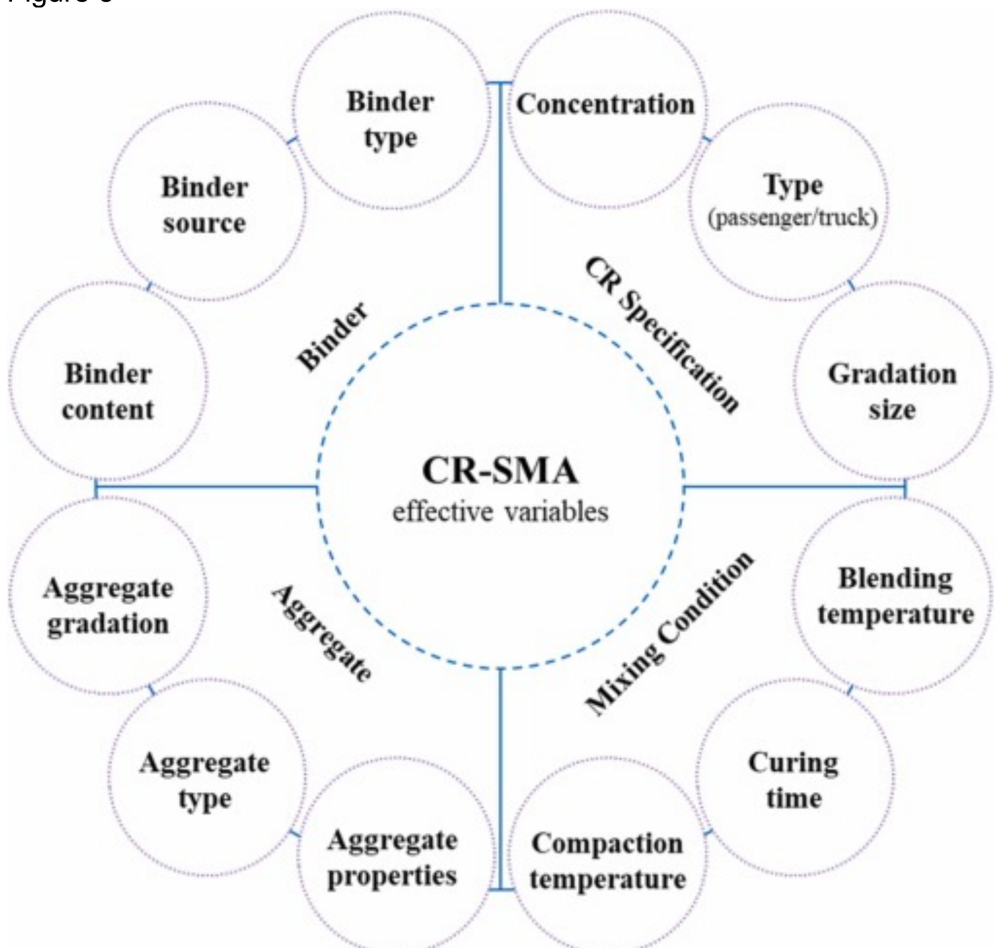


Figure 5



VOCAB: (w/definition)	**Ambient** – refers to the surrounding environmental conditions, usually room temperature **Aggregate gradation** – the distribution of different particle sizes within the aggregate used in an asphalt mixture

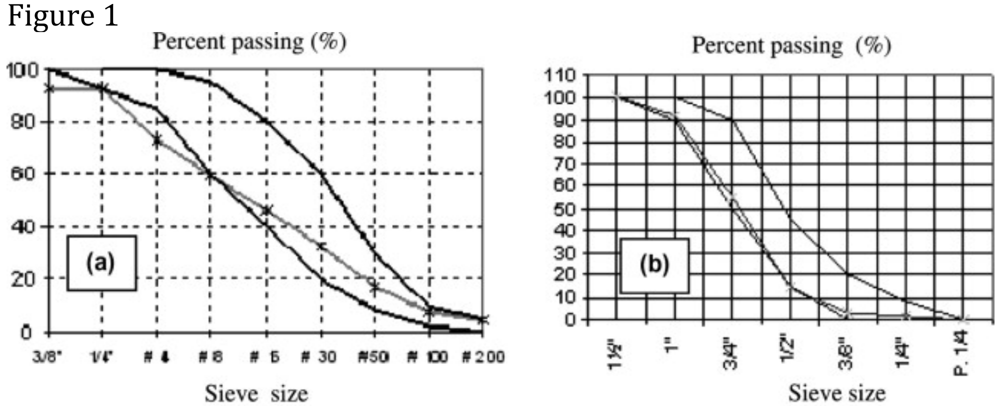
	Crumb rubber (CR) – tiny granules made from recycled tires **Devulcanization** – a chemical process that breaks down the cross-linked sulfur bonds in vulcanized rubber, making it softer and more able to blend with asphalt binder
Cited references to follow up on	https://www.sciencedirect.com/science/article/pii/S0959652611004215 https://www.emerald.com/jgrim/article-abstract/175/1/3/403204/Advances-in-ground-improvement-using-waste?redirectedFrom=fulltext https://www.sciencedirect.com/science/article/pii/S0921344904000643
Follow up Questions	Can a similar process be done with a different material? How does this change with binder content?

Article #11 Notes: Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios

Article notes should be on separate sheets

Source Title	Science Direct
Source citation (APA Format)	Albano, C., Camacho, N., Hernández, M., Matheus, A., & Gutiérrez, A. (2009). Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios. *Waste Management*, *29*(10), 2707–2716. https://doi.org/10.1016/j.wasman.2009.05.007
Original URL	https://www.sciencedirect.com/science/article/pii/S0956053X09001767
Source type	Journal Article
Keywords	Water-to-cement; concrete; PET; particle size
#Tags	#Concrete #PET
Summary of key points + notes (include methodology)	The study investigates how recycled PET from bottles affects the mechanical and thermal behavior of concrete. They compared the water-to-cement ratio (w/c) of 0.5 and 0.6. They also compared the PET content by using 10% and 20% by volume which replaced the sand. Finally, they used 3 different sizes: small (0.26 cm), large (1.14 cm), and mixed (50/50) and examined how these composites behaved under 200 ºC, 400 ºC, and 600 ºC. They evaluated for mechanical, thermal, and non-destructive properties. They used Portland cement, river sand for a fine aggregate and crushed stone for a coarse aggregate. They used 150x300 mm cylinders for compression and tensile tests, and 200x200x50 slabs for flexural and heat tests. They cured the concrete at 7, 14, 28, and 60 days in water between 23 and 27 ºC. They used the slump test, compressive strength, splitting tensile strength, modulus of elasticity, and flexural strength before and after heating. They measured PET degradation using Thermogravimetric Analysis (TGA) under nitrogen. Furthermore, they tested for water absorption by comparing the dry and not dry weights, and used an ultrasonic pulse velocity test to measure density, homogeneity, and defects. They found that adding

<table>
<tr><td></td><td>PET reduces slump, and 10% PET improved flow slightly, although 20% PET led to compaction issues. Overall, mixed particle sizes gave better workability and fewer voids. Most of the mechanical properties went down with the PET, although its water absorption was higher. Overall, they found that including PET reduces strength but improves ductility and reduces weight. They found that the best results were when it had 10% PET with small or mixed sizes and w/c of 0.5.</td></tr>
<tr><td>Research Question/Problem/ Need</td><td>How do the content and particle size of recycled PET aggregates influence the properties and behaviors of concrete.</td></tr>
<tr><td>Important Figures</td><td>Figure 1



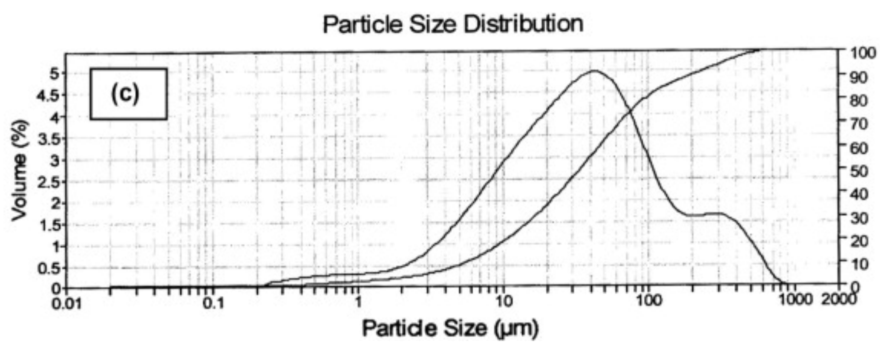


Figure 3</td></tr>
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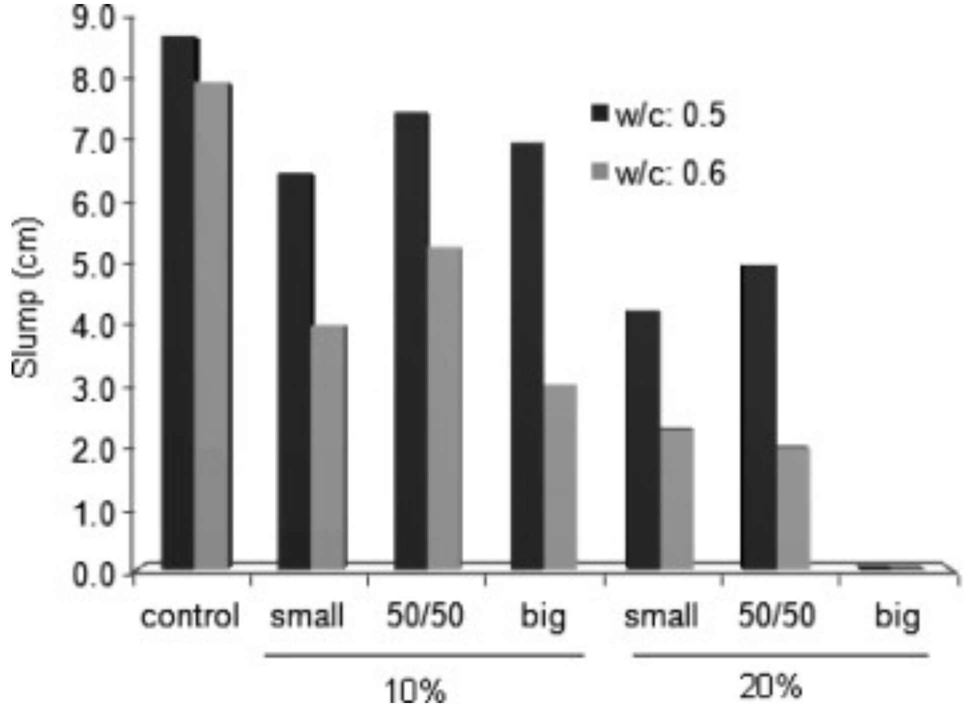
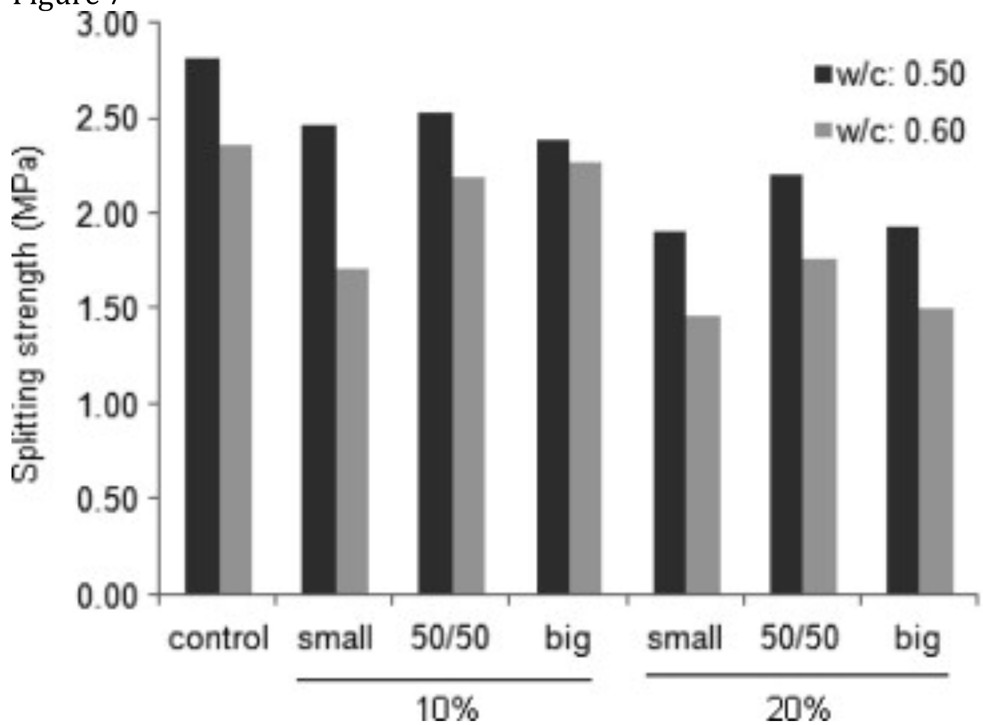


Figure 7



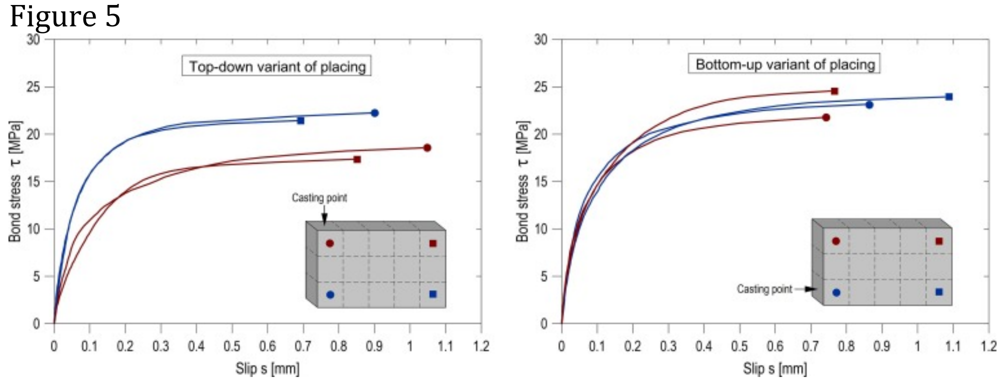
VOCAB: (w/definition)	Slump Test – a test that measures concrete's workability by how much a cone-shaped sample "slumps" when the mold is removed. Curing – the process of keeping concrete moist and at proper temperature so it can develop strength over time Thermal Degradation – breakdown of a material due to high

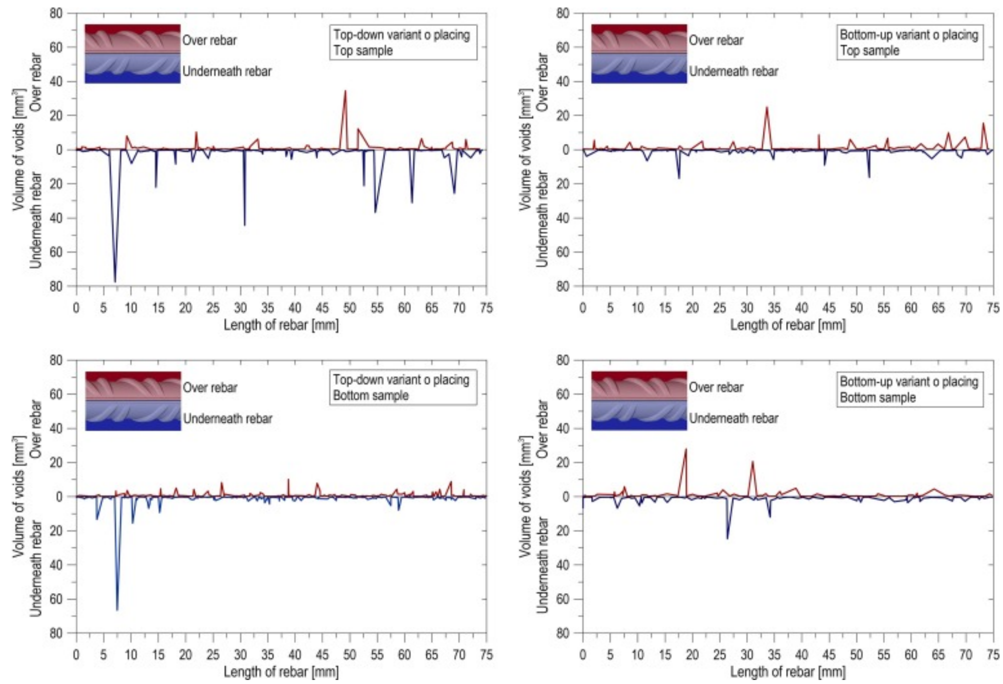
	temperature Porosity – the amount of tiny holes or voids in a material; higher porosity means lower strength and higher water absorption Thermogravimetric Analysis (TGA) – a test measuring weight changes as a material is heated to study its decomposition
Cited references to follow up on	https://www.sciencedirect.com/science/article/pii/S0008884604002169 https://www.sciencedirect.com/science/article/pii/S0141391005001357
Follow up Questions	Why did the mix with 10% PET perform better than the mix with 20% PET? What factors effect flexural strength of concrete? How can PET concrete be used? How might PET fibers instead of aggregates change the results?

Article #12 Notes: Effect of bottom-up placing of self-compacting concrete on microstructure of rebar-concrete interface

Article notes should be on separate sheets

Source Title	Science Direct
Source citation (APA Format)	Dybeł, P. (2021). Effect of bottom-up placing of self-compacting concrete on microstructure of rebar-concrete interface. *Construction and Building Materials*, *299*, 124359. https://doi.org/10.1016/j.conbuildmat.2021.124359
Original URL	https://www.sciencedirect.com/science/article/pii/S0950061821021188
Source type	Journal Article
Keywords	Self-compacting concrete; admixture; superplasticizer; bottom-up placing; concrete; rebar
#Tags	#concrete
Summary of key points + notes (include methodology)	The study investigates how the method of placing self-compacting concrete (SCC) bottom up or top down affects the microstructure of the rebar-concrete interface as well as the bond strength and mechanical performance between rebars and the surrounding concrete. They hypothesized the bottom-up casting would improve performance due to more uniform compaction and reduced air entrapment. Methodology - Made self-compacting concrete (SCC) - Used Portland cement - Water to cement ratio of 0.36 - Aggregates were natural sand and crushed stone with a max size of 16mm - They used a polycarboxylate-based superplasticizer to ensure flowability - The concrete was tested for bonding and bond strength using cylinders of 160mmx320mm using a pull-out test - They tested compressive and tensile splitting strength to confirm consistency - They analyzed the microstructural analysis using Scanning Electron Microscopy (SEM) and image analysis on the interfacial

	transition zone (ITZ) They found that both the top-down and bottom-up mixes achieved similar compressive strength of around 65 MPa and tensile strength of around 4.5 Mpa, which confirms that the mix quality for both with consistent. As such, the difference in results were solely attributed to placement method. The results showed that the bond strength of bottom-up casting was higher about 10-20% on average and that the bond stiffness was higher and was more compact, leading to higher adhesion. The results also showed the load-slip behavior was smooth and more ductile meaning that there was more uniform stress transferred along the rebar. They observed that bottom-up casting had a denser ITZ with fewer voids and improved adhesion. They also improved that the contact between rebar and concrete was more consistent. Overall, it implied that bottom-up placing is especially beneficial for structures that need denser concrete or might be more complex where it cannot just self compact from gravity alone.
Research Question/Problem/ Need	The goal was to determine whether bottom-up casting improves bond performance and microstructural quality.
Important Figures	Figure 5  Figure 8

	
VOCAB: (w/definition)	**Admixture –** a chemical substance added to concrete (other than water, cement, or aggregates) to modify its properties **Superplasticizer** – a high-range water-reducing admixture that greatly increases the fluidity of concrete without adding water **Scanning Electron Microscopy (SEM)** – an advanced microscope that uses a focused beam of electrons to create high-resolution images of a material's surface **Interfacial Transition Zone** – the thin layer of material between the aggregate or rebar surface and the surrounding cement paste **Load-Slip Behavior –** the relationship between the applied load and the resulting movement of the rebar within the concrete during a pull-out test **Rebar –** a steel rod embedded in concrete to improve its tensile strength
Cited references to follow up on	http://ndl.ethernet.edu.et/bitstream/123456789/75013/1/89.pdf https://www.sciencedirect.com/science/article/pii/S0950061818316994
Follow up Questions	Why did the researcher choose to use self-compacting concrete? Why did they use 0.36 water-cement ratio? Why was there no significant difference in compressive strength, even though bond strength improved?

Article #13 Notes: A novel material for lightweight concrete production

Article notes should be on separate sheets

Source Title	Science Direct
Source citation (APA Format)	Kan, A., & Demirboğa, R. (2009). A novel material for lightweight concrete production. *Cement and Concrete Composites*, *31*(7), 489–495. https://doi.org/10.1016/j.cemconcomp.2009.05.002
Original URL	https://www.sciencedirect.com/science/article/pii/S0958946509000808
Source type	Journal Article
Keywords	Lightweight concrete; MEPS; EPS; artificial aggregate; recycling
#Tags	#concrete

Summary of key points + notes (include methodology)	This study aimed to improve concrete made with expanded polystyrene (EPS) aggregates as it is oftentimes very light but weak. They tried to do so by creating modified expanded polystyrene (MEPS) aggregates through a thermal treatment process and then they tested their potential use in lightweight concrete.
	Methodology
	- Made MEPS aggregates by heating waste EPS foams at 130 ºC for 15 minutes in a hot air volume
	  ○ This reduced volume, increased strength, and improved surface bonding potential
	- They also used Portland cement, natural sand (fine aggregate) with sizes between 0 and 4 mm, and crushed gravel (coarse aggregate) with sizes between 4 and 16 mm
	- Used a superplasticizer which was a polycarboxylate-based admixture
	- They had six different aggregate ratios
	  ○ 50% fine MEPS and 50% coarse MEPS
	  ○ 75% MEPS and 25% sand
	  ○ 50% coarse MEPS and 50% sand
	  ○ 50% fine MEPS and 50% gravel
	  ○ 50% MEPS and 50% of sand and gravel together

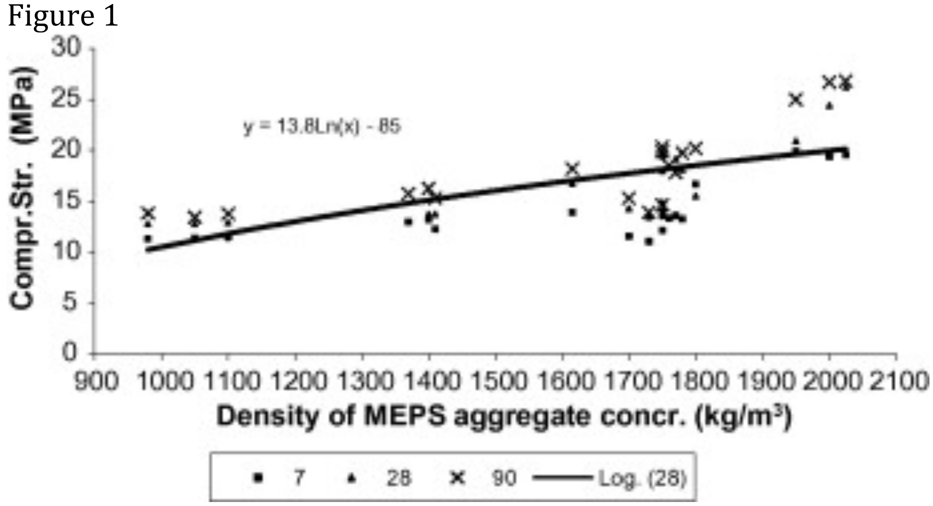
<table>
<tr><td></td><td>
o Control: 25% fine MEPS and 75% of sand and gravel together
- All mixes used a 0.38 to 0.43 w/c ratio
- They tested the concrete at 7, 28, and 90 days after curing in water at 17 ºC to 23 ºC
- They tested for workability, density, compressive strength, splitting tensile strength, ultrasonic pulse velocity, and freeze-thaw resistance
- Findings
o Increasing MEPS content reduced workability due to high porosity and surface area
o Superplasticizers were essential to maintain flow
o Density decreased greatly with higher MEPS, and the concrete became lightweight
o The compressive strength decreased with increasing MEPS content, although fine MEPS aggregates improved bond strength more than coarse MEPS
o Ultrasonic pulse velocity indicated that it is stronger and more compact with less MEPS
o Splitting tensile strength indicated that MEPS concrete failed in a similar brittle manner to normal concrete
o Resistance to freezing and thawing improved with greater fine MEPS, with 50% fine MEPS and 50% coarse aggregate performing the best; overall, all mixes showed good resistance
- The environmental benefit is that MEPS reuses plastic waste and reduces the amount of natural aggregate being used
</td></tr>
<tr><td>Research Question/Problem/ Need</td><td>Can MEPS aggregates be an effective alternative as a lightweight aggregate in concrete?</td></tr>
<tr><td>Important Figures</td><td>
Figure 1


Figure 2
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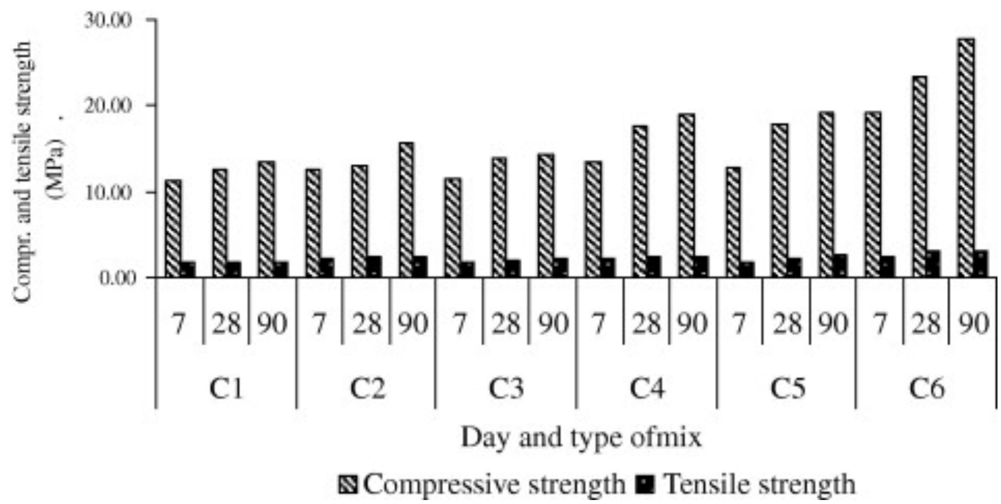


</td>
</tr>
<tr>
<td>VOCAB: (w/definition)</td>
<td>Expanded Polystyrene – a lightweight plastic foam used in packaging and insulation
Specific Gravity – the ratio of a material's density compared to water
Freeze-Thaw Resistance – the ability of concrete to withstand cycles of freezing and thawing without cracking or losing strength</td>
</tr>
<tr>
<td>Cited references to follow up on</td>
<td>https://www.academia.edu/download/123043298/IJEMS_20142_202007_20158-162.pdf
https://www.sciencedirect.com/science/article/pii/S0950061804000066</td>
</tr>
<tr>
<td>Follow up Questions</td>
<td>Why did the researchers use thermal treatment to modify EPS?
Why did fine MEPS aggregates improve the freeze-thaw resistance more than coarse MEPS?
Where can this be used?
Could fiber reinforcements help improve MEPS concrete strength?</td>
</tr>
</table>

Article #14 Design and Performance of Stone Mastic Asphalt

Article notes should be on separate sheets

Source Title	ASCE Library
Source citation (APA Format)	Qiu, Y. F., & Lum, K. M. (2006). Design and Performance of Stone Mastic Asphalt. *Journal of Transportation Engineering*, *132*(12), 956–963. https://doi.org/10.1061/(ASCE)0733-947X(2006)132:12(956)
Original URL	https://ascelibrary.org/doi/full/10.1061/%28ASCE%290733-947X%282006%29132%3A12%28956%29
Source type	Journal Article
Keywords	Stone mastic asphalt; mix design; rutting; stone-to-stone; bailey method
#Tags	#SMA #asphalt #design #properties

Summary of key points + notes (include methodology)	This study aims to develop a mix design procedure to quantify stone-to-stone contact using a modified Bailey Method. They adapted the Bailey Method to evaluate aggregate packing and gradation by volume not weight. The aggregates were divided into coarse aggregates and fine aggregates and fillers which they distinguished between using a break point sieve.
	Methodology
	- They tested 16 SMA mixtures with 6 aggregate gradations and 3 asphalt binder contents
	- They used crushed granite as the aggregate and a polymer-modified bitumen to prevent drain down
	- The mineral filler was always 10% across all mixtures
	- They tested the aggregate packing using loose and rodded unit weights (LUW and RUW) to determine the level of interlock
	- They compacted the mixtures using a Servopac Gyratory Compactor to simulate field compaction
	- Evaluated 4 categories in the sample:
	    o Voids in the total mix
	    o Voids in the mineral aggregate

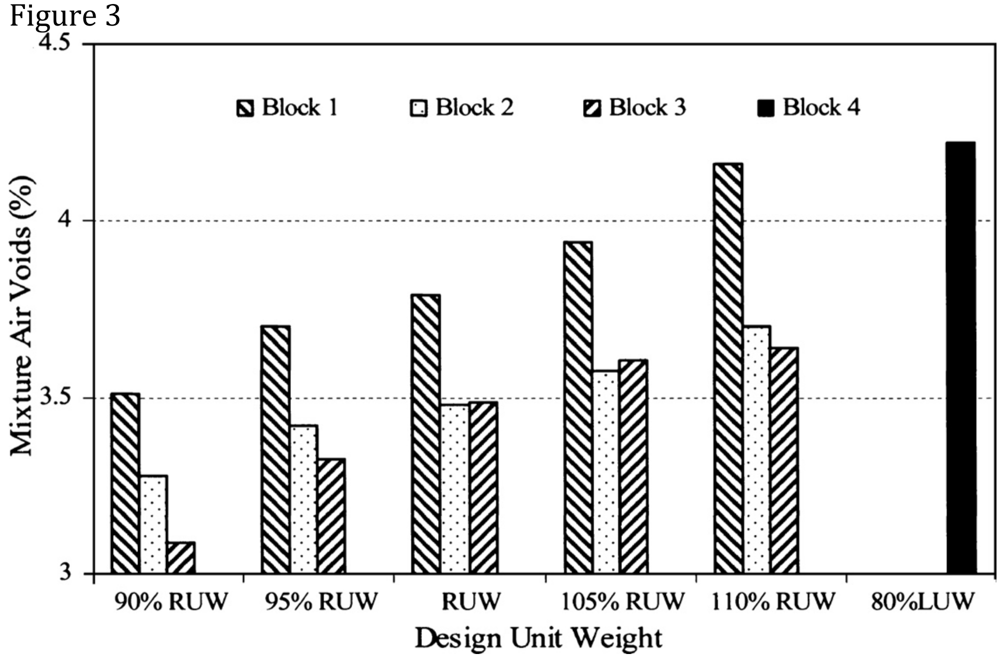
<table>
<tr><td></td><td>
Voids in the coarse aggregate
Voids filled with asphalt
They then tested on the mechanical properties:
They did a creep test to assess the permanent deformation under a repeated load; found that permanent strain decreased as coarse aggregate volume increased up to 105% RUW which indicated optimal stone-to-stone contact between 95% and 105% RUW; 5.5% binder had the least deformation
They then simulated rutting under wheel loads at 50 ºC; found that the lowest rut depth was at 105% RUW, and that SMA mixes showed less rutting than dense-graded mixes
They then used statistical analysis to see that asphalt content and aggregate volume both significantly affect deformation and that asphalt binder content was the more sensitive variable
They found a strong correlation (r-squared being 0.82) between rutting and permanent strain. They also found that SMA outperformed dense-graded mixtures in rutting resistance and stability. They concluded that the adapted Bailey Method effectively quantified aggregate interlock and packing in SMA design.
</td></tr>
<tr><td>Research Question/Problem/ Need</td><td>How can a reliable mix design method be developed for SMA that ensures stone-to-stone contact and optimal qualities?</td></tr>
<tr><td>Important Figures</td><td>Figure 3


Figure 6</td></tr>
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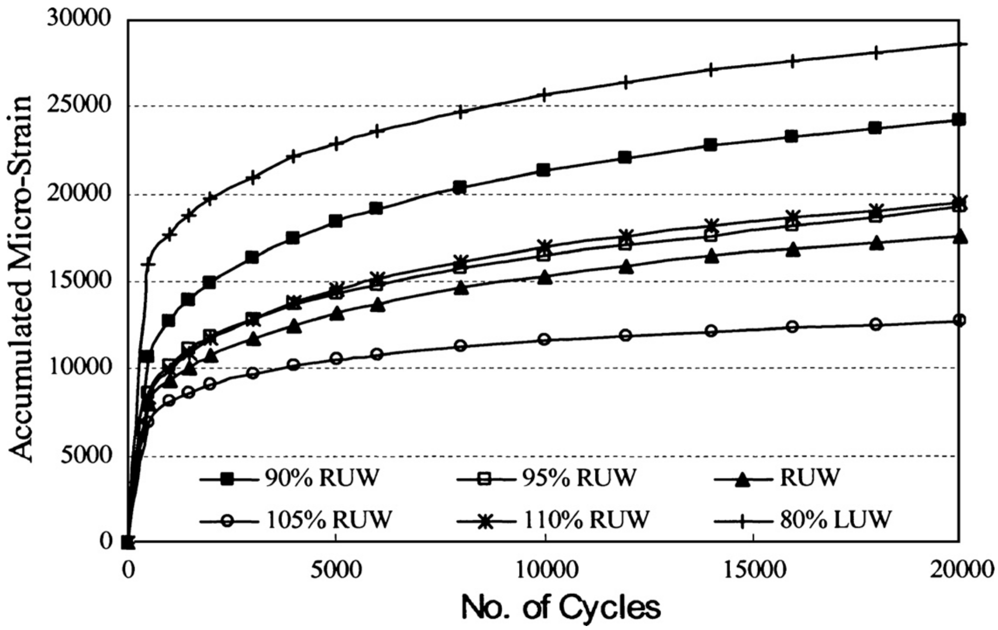
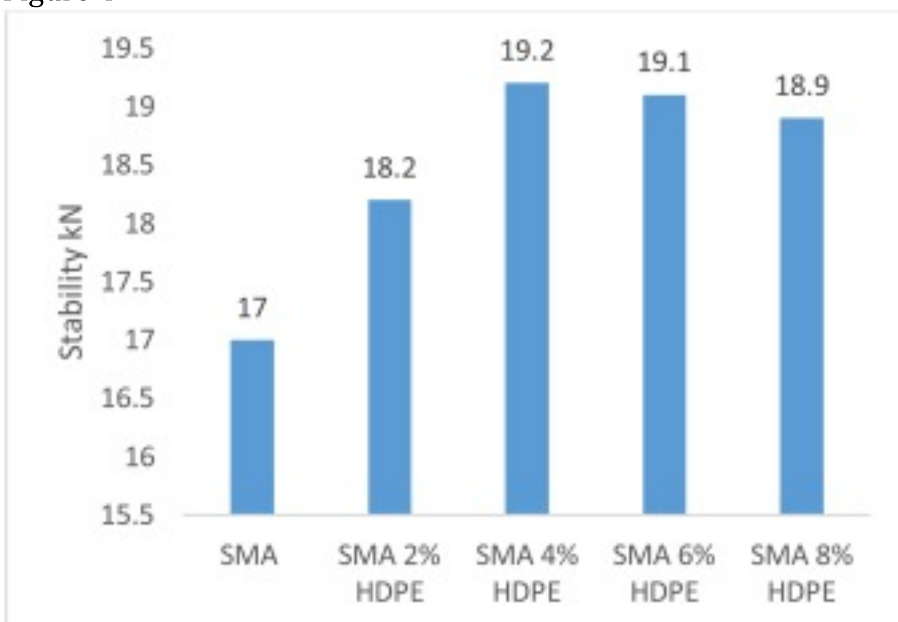
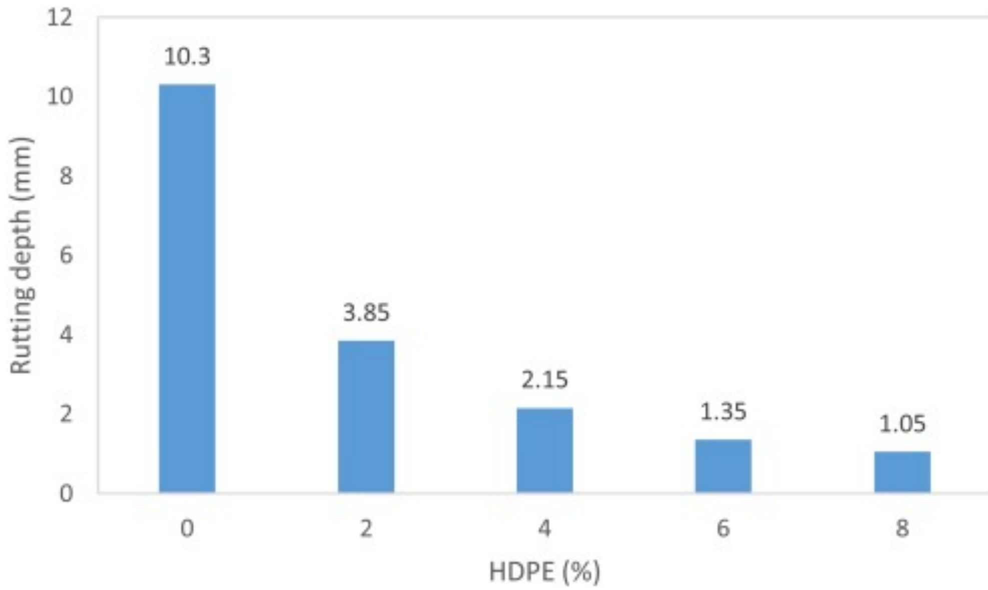
<tr><td></td><td>
</td></tr>
<tr><td>VOCAB: (w/definition)</td><td>Loose Unit Weight – the density of coarse aggregates placed loosely without compaction; is used to estimate voids and packing potential
Rodded Unit Weight – the bulk density of compacted coarse aggregates measured in a container</td></tr>
<tr><td>Cited references to follow up on</td><td>https://books.google.com/books?hl=en&lr=&id=iotFurBLFwIC&oi=fnd&pg=PA5&ots=1iPhXzoiGI&sig=1_I38kC2-W7OwXFoO197zZNWyoo#v=onepage&q&f=false
https://www.emerald.com/jtran/article-abstract/156/1/43/423962/Binder-influence-type-on-deformation-resistance-of?redirectedFrom=fulltext</td></tr>
<tr><td>Follow up Questions</td><td>Why the Bailey Method?
How was RUW used?</td></tr>
</table>

Article #15 Notes: Mechanical properties of stone mastic asphalt containing high-density polyethene: An Australian case

Article notes should be on separate sheets

Source Title	Science Direct
Source citation (APA Format)	Chegenizadeh, A., Peters, B., & Nikraz, H. (2021). Mechanical properties of stone mastic asphalt containing high-density polyethene: An Australian case. *Case Studies in Construction Materials*, *15*, e00631. https://doi.org/10.1016/j.cscm.2021.e00631
Original URL	https://www.sciencedirect.com/science/article/pii/S2214509521001467
Source type	Journal Article
Keywords	Stone mastic asphalt; High-density polyethene; Asphalt; Fatigue; Rutting
#Tags	#SMA #recycling #design
Summary of key points + notes (include methodology)	The study wanted to see how adding high-density polyethylene (HDPE) affects the mechanical properties and performance of SMA mixtures. Methodology - Aggregates were crushed stone, sand, hydrated lime - They used 6.5% C320 bitumen for binder - Added HDPE at 2, 4, 6, and 8% by weight of binder - They used 0.3% cellulose fiber to prevent drain down - They mixed at around 135-160 ºC and dried the aggregates at 140-160 ºC, and heated the bitumen at 160 ºC - The mixed the HDPE with bitumen for 3 hours at 160 ºC and added hot binder to hot aggregates in a Hobart mixer - They compacted according to the MRWA asphalt design - They tested for Marshall stability and flow to evaluated strength, workability, and deformation under load - They also tested maximum density using the rice method to determine the theoretical maximum specific gravity

	- They found the voids in the mineral aggregate to see the structure - They used a four-point bending fatigue tests to measure resistance to repeated flexural loading - They used a wheel tracking test to simulate rutting under wheel loads at high temperature They found that HDPE can successfully be used as a modifier. 4% HDPE is best for fatigue life and overall durability while 8% HDPE is best for rutting resistance under heavy loads. HDPE also reduces road maintenance cost and is more sustainable. They indicated that future work could focus on long-term aging and actual field testing.
Research Question/Problem/ Need	How does HDPE as a bitumen modifier affect the mechanical properties of SMA under Australian conditions?
Important Figures	Figure 4  Figure 9

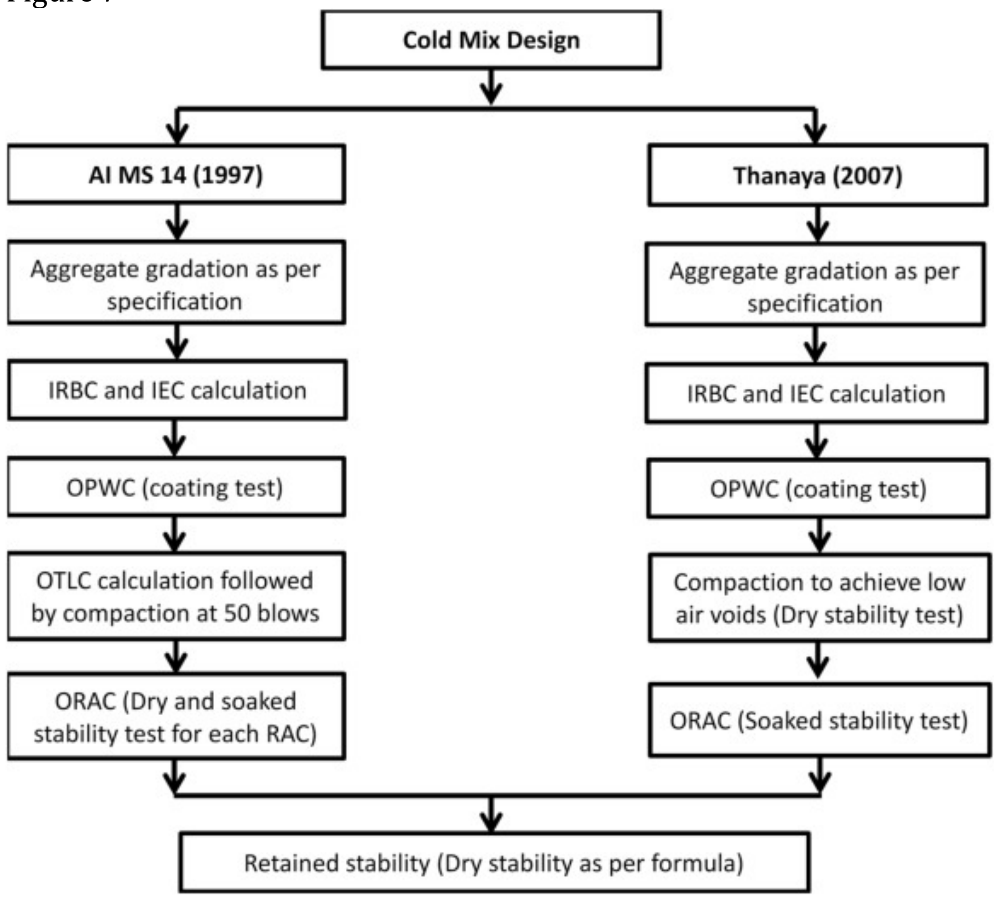
	
VOCAB: (w/definition)	**High-Density Polyethylene (HDPE) –** a thermoplastic polymer made from petroleum
Cited references to follow up on	https://www.sciencedirect.com/science/article/pii/S0261306911004225 https://ascelibrary.org/doi/abs/10.1061/(ASCE)TE.1943-5436.0000395
Follow up Questions	How does HDPE act in the mixture? How did it affect workability and compactability? Why those percentages tested?

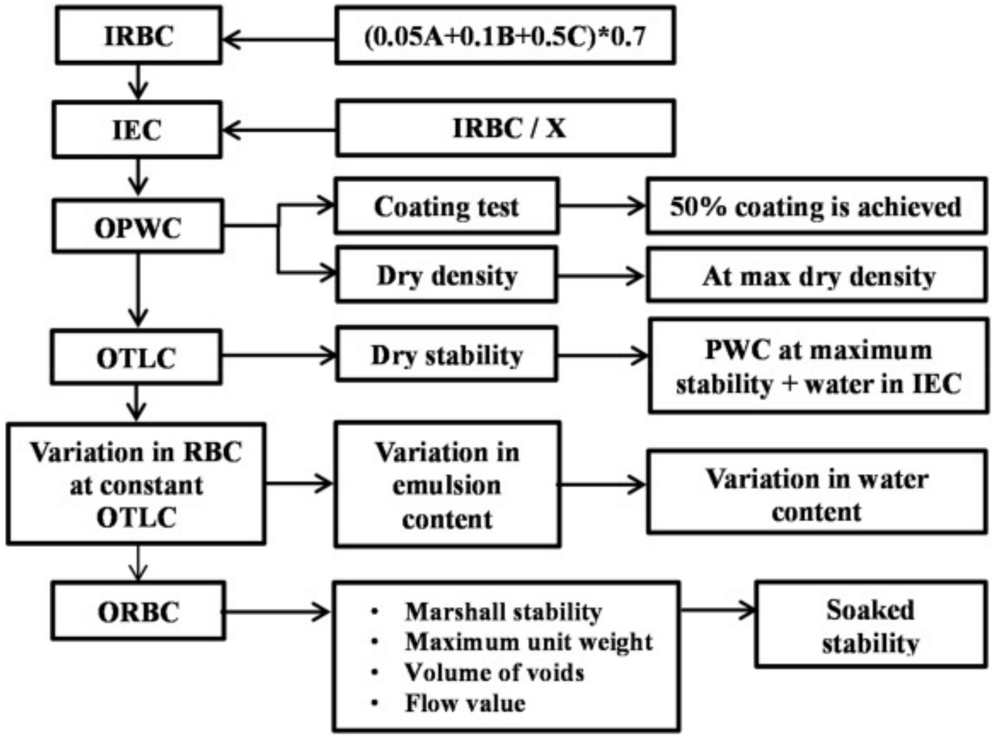
Article #16 Notes: Cold mix asphalt: An overview

Article notes should be on separate sheets

Source Title	Science Direct
Source citation (APA Format)	Jain, S., & Singh, B. (2021). Cold mix asphalt: An overview. *Journal of Cleaner Production*, *280*, 124378. https://doi.org/10.1016/j.jclepro.2020.124378
Original URL	https://www.sciencedirect.com/science/article/pii/S0959652620344231
Source type	Journal Article
Keywords	Cold mix asphalt (CMA) Emulsion Cutback
#Tags	#CMA #design
Summary of key points + notes (include methodology)	Cold mix asphalt (CMA) can help reduce the carbon emission of the highway industry. This type of asphalt uses asphalt emulsion and cutback as the binder which are liquid at room temperature; there is no heating required for mixing and compaction. Even so, CMA has worse performance, so it is generally not used in high density traffic. - Benefits: ○ cold recycling; easy to set up, mobile, quick, energy efficient, and little energy needed, better for smog days ○ less fuel usage due to no heating ○ less greenhouse gas emissions ○ less energy usage = less financially ○ possible to pave in winter season + less road construction time - Cons: ○ Fails in required strength and stability requirements; Marshall Stability values are much lower; means it must be used in lower traffic density areas such as rural roads ○ Water is used in preparation which affects the interaction between aggregate and binder = reduced adhesion which cause rutting, fatigue cracking, stripping, etc. ○ Rutting also created by reduced binder aging from lower

	temperature o Additives, fillers, other materials used to improve performance changes its low cost and environmental impact o Using cutback for CMA results in petroleum fumes which can be a fire hazard - Materials o Binder: emulsion and cutback ▪ Emulsion generally has 60% bitumen + 40% water ▪ When in contact w/ aggregates it breaks down and mix begins to set ▪ Cationic emulsion suitable for most aggregate; has higher strengths and elastic modulus; pH of mixture may rise quickly ▪ Most studies recommend medium/slow setting emulsion ▪ Cutback is prepared by mixing solvents such as kerosene, diesel oil, furnace oil, etc. with the bitumen; reduces viscosity to prepare the mix at lower temperatures o Aggregates: usually crushed rocks, slag, gravels o Water is used to lubricate the aggregates which improves workability and coating aggregates; water should be potable - SUPERPAVE cold mix design in the USA - Need to calculate initial residual bitumen content (IRBC); changes in initial emulsion content (IEC) which is the amount of emulsion required to make the required IRBC; optimum prewetting water content (OPWC), which depends on type of mix such as dense vs open graded; optimum total liquid content (OTLC) is the sum of water already present in emulsion and extra water added in mixing' optimum residual bitumen content (ORBC) is the bitumen content to get the optimum values of Marshall design parameters - 50 blows compaction level recommended as higher blows are difficult to achieve - Samples can also be made using the Superpave mix design method which uses a gyratory compactor from an angle of 1º to 6º. This produces kneading action which simulates field compaction better than the Marshall impact hammer. - In dry conditions limestone showed better resistance to moisture damage, in damp conditions granite showed better adhesion - Curing depends on climatic conditions; 14 days of curing at 35º C temperature and 20% relative humidity is optimum; curing is one of the most important factors for cold mix performance

	- There have been multiple different types of additives tested in CMA: cement, fly ash, lime, chemical additive, fibers, RAP, etc.
Research Question/Problem/ Need	Pros and cons of cold mix asphalt as well as effects of different methods.
Important Figures	Figure 7  Figure 8



VOCAB: (w/definition)	**Situ** – in its original place
Cited references to follow up on	https://trid.trb.org/View/885957 https://ascelibrary.org/doi/abs/10.1061/(ASCE)MT.1943-5533.0000540
Follow up Questions	What are the optimal percentages for each material in CMA? What affects curing time the most?

Article #17 Notes: Mechanical properties of an upgrading cold-mix asphalt using waste materials

Article notes should be on separate sheets

Source Title	ASCE Library
Source citation (APA Format)	Al-Busaltan, S., Al Nageim, H., Atherton, W., & Sharples, G. (2012). Mechanical properties of an upgrading cold-mix asphalt using waste materials. *Journal of Materials in Civil Engineering*, *24*(12), 1484–1491. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000540
Original URL	https://ascelibrary.org/doi/abs/10.1061/(ASCE)MT.1943-5533.0000540
Source type	Journal Article
Keywords	CMA Cold mix asphalt Waste
#Tags	#CMA #design
Summary of key points + notes (include methodology)	Cold bituminous emulsion mixtures (CBEMs) have seen improvements in mechanical properties from 0 to 5.5% of aggregate mass in the mixture being waste products. Methodology: - They used crushed green granite and aggregate sizes that were under 14mm; the aggregate was dried, riffled, and bagged - They used 0/10mm close graded surface coarse gradation - The densities of the coarse and fine aggregates were almost exactly 50/50 - Thet used cationic, slow setting bituminous emulsion (K3) and they compared it with 53 and 143 penetration grade hot mix asphalt - They prepared the samples according to the method adopted by the Asphalt Institute (MS-14) - They conducted indirect tensile strength tests to determine the optimum emulsion content and mix density test to determine the

	optimum total liquid content at compaction; found pre-wetting water content to be 4%, optimum bitumen emulsion to be 11.5%, and optimum total liquid content at 14.5% - LJMU-FA1 was used as a replacement for mineral filler with percentages between 0 and 5.5 - They used impact compacting with a Marshall Hammer with 50 blows on each face of the specimens - The HMA were prepared with the same aggregate type and gradation with a 5.3% binder content as a comparison - The 0% CMA was used as a control - All samples were prepared in 3 1,100g specimens for each mix - Cold mix were mixed and compacted at lab temperature (20-25ºC) while hot mix were compacted at 135-140 ºC - They first cured for 24h for 20ºC and then tested the curing at different temperatures and ages (20, 40, 60ºC + 2, 7, 14, 28, 90, 180 days) for stiffness modulus and indirect tensile testing - For uniaxial compressive cyclic testing, the specimens were left in their molds for 24h at room temperature and then placed in an oven for 14 days at 40ºC - Five specimen were prepared and tested to represent each single test result They found that the stiffness modulus of CBEMs increased with increased percentage of LJMU-FA1 and worked best when the mineral filler was completely replaced with it. They also found that the ITSM values showed to increase with increasing curing temperatures as well as with more replacing mineral filler. Specimens with higher waste content has considerably longer life under cyclic load creep testing when compared with HMA; the specimen with 5.5% LJMU-FA1 had a creep stiffness approximately 26 times higher than the control under the same testing conditions. Water sensitivity, which is measured with indirect tensile strength ratio (ITSR) or indirect tensile stiffness modulus ratio (SMR), found that the SMR increases from 45.5% for the control to 120.6% for the 5.5% sample. They also found that there was a hydration process related to LJMU-FA1 which led to stiffening of the bituminous binder.
Research Question/Problem/ Need	What does the incorporation of LJMU-FA1 do to the mechanical properties of CMA?
Important Figures	Figure 2

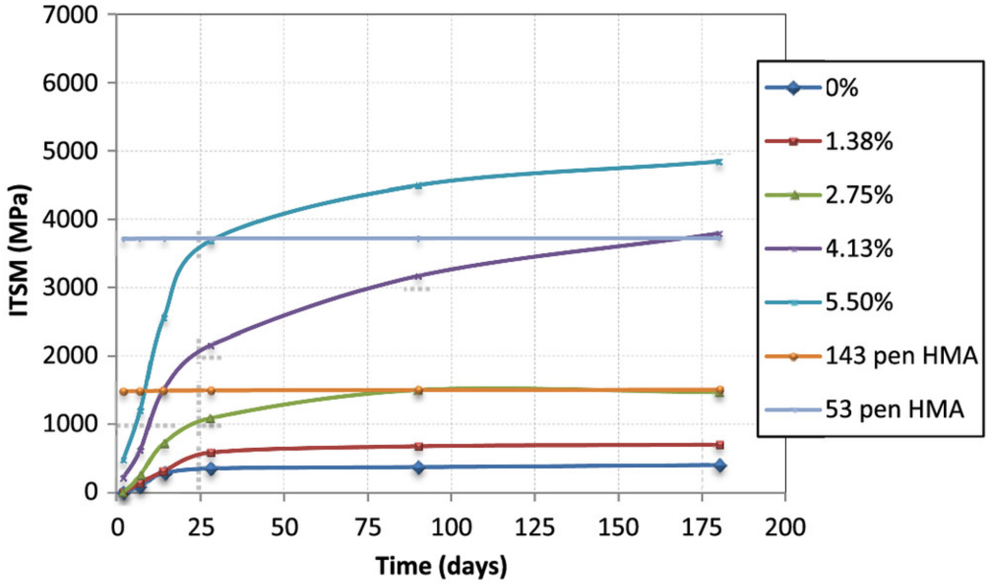


Figure 4

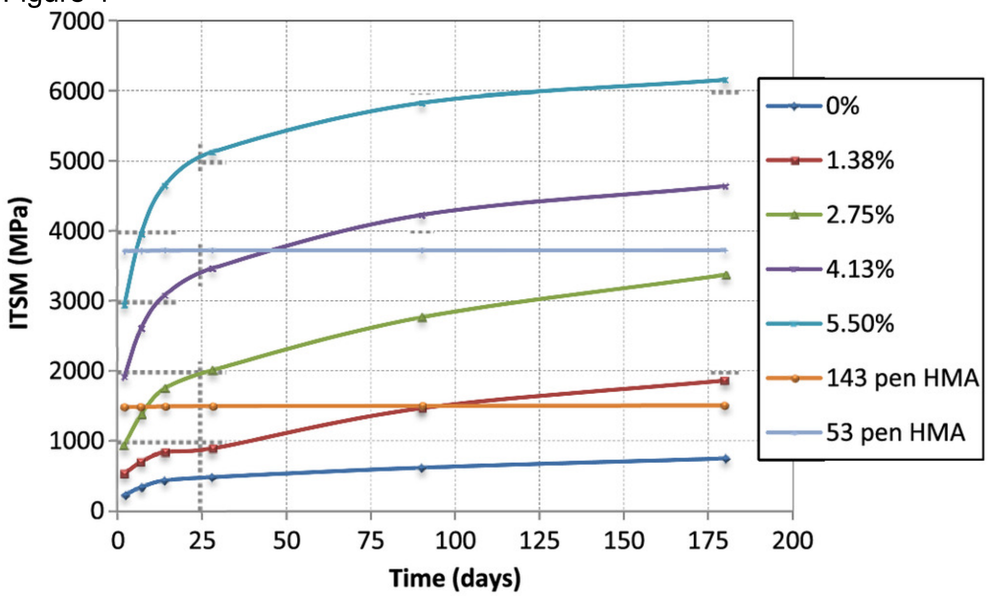
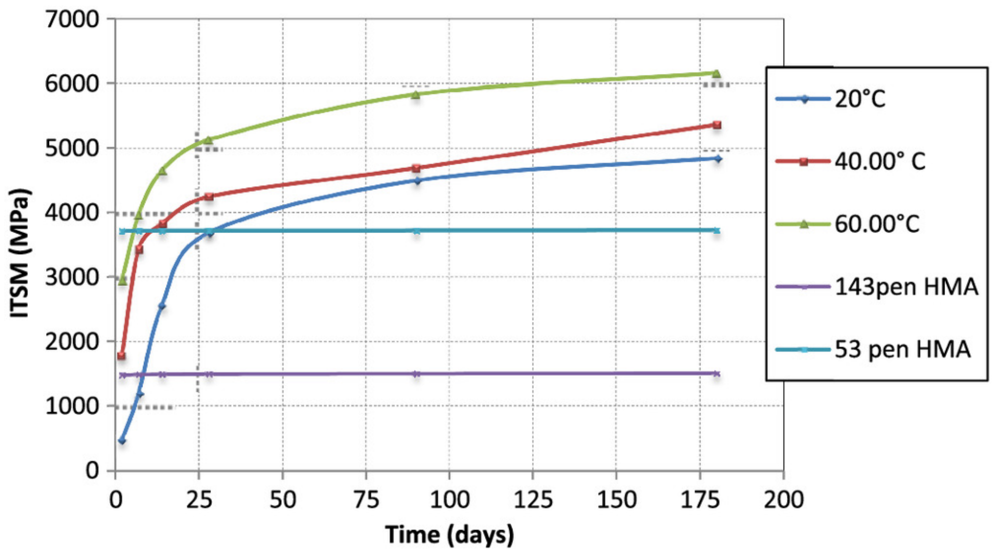


Figure 5

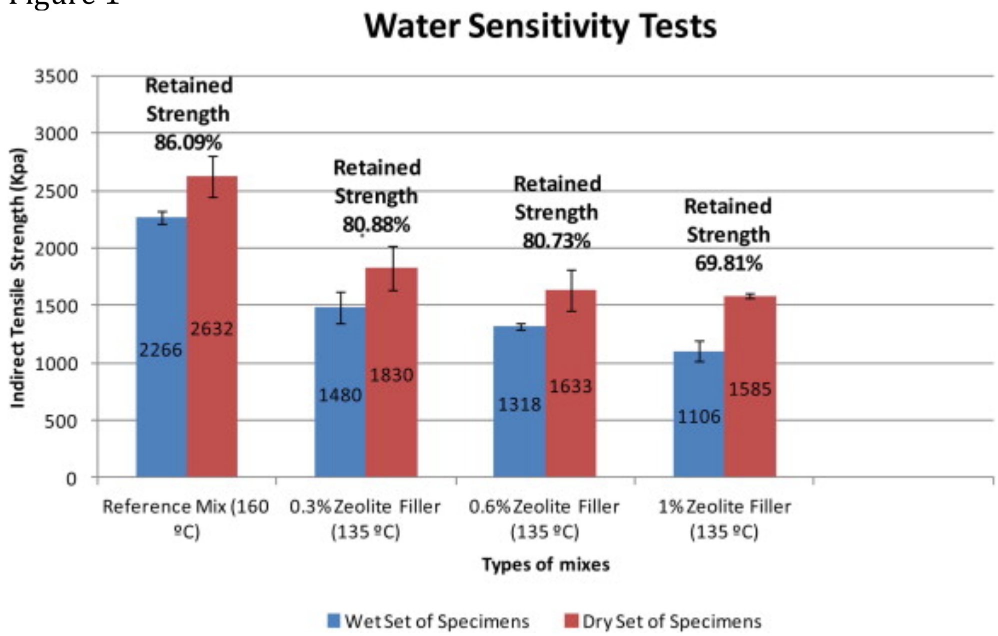
	
VOCAB: (w/definition)	**LJMU-FA1** – a type of waste fly ash **Uniaxial Compressive Cyclic Testing** – a method used to determine a material's strength and deformation properties by repeatedly applying and releasing a compressive load along one axis
Cited references to follow up on	https://etheses.whiterose.ac.uk/id/eprint/386/ https://www.emerald.com/jtran/article-abstract/162/1/47/417113/A-laboratory-study-on-cold-mix-cold-lay-emulsion?redirectedFrom=fulltext
Follow up Questions	Why did they end at 5.5% LJMU-FA1? What was the best aging?

Article #18 Notes: Warm mix asphalt: An overview.

Article notes should be on separate sheets

Source Title	Science Direct
Source citation (APA Format)	Rubio, M. C., Martínez, G., Baena, L., & Moreno, F. (2012). Warm mix asphalt: An overview. *Journal of Cleaner Production*, *24*, 76–84. https://doi.org/10.1016/j.jclepro.2011.11.053
Original URL	https://www.sciencedirect.com/science/article/pii/S0959652611004926
Source type	Journal Article
Keywords	Warm mix asphalt Pavement Cleaner production
#Tags	#WMA
Summary of key points + notes (include methodology)	Literature review - Uses U.S. FHWA documents - Technical reports, field evaluations from European countries, academic theses, technology reports and industry research centers They compare foaming technologies, organic additives, and chemical additives on how each reduces temperature, dosage requirements, equipment modifications, and performance impacts. They use published data on moisture sensitivity, rutting, volumetrics, RAP incorporation, temperature and compaction behaviors, and environmental emission reductions. They also compare the costs and review the mix design approaches. Foaming processes (Foam formed by injecting water or releasing water from zeolites) - Reduces viscosity temporarily; improves coating and workability - Two types: water-containing and water-based - Risks: insufficient foaming means poor coating and moisture susceptibility Organic additives (waxes such as Sasobit, Montan wax, amide waxes) - Melt at production temperatures, reducing viscosity

	- Solidify on cooling; increases stiffness and rut resistance - Must avoid low melt-point waxes to prevent softening in-service Chemical additives (surfactants, polymers, emulsifies) - Improve coating and compaction - Reduces temperature Mix design considerations - Aggregate gradation; same as HMA gradation - Additive dosage - Laboratory mixing - RAP incorporation o WMA can have higher RAP percentages due to improved workability - Production and compaction temperatures - Bitumen selection - Bitumen content Performance findings - WMA typically performs as well as or sometimes better than HMA - Better compaction Concerns - Moisture susceptibility - Potential for rutting - Need for appropriate curing - Long-term aging data still limited Benefits - Temperature reduction = emission reduction - Better for worker health and indoor environments - Less fuel consumption - Improved durability - Higher RAP potential - Lower aging of binder - Better compaction - Longer haul distances - Extended paving season Drawbacks - Moisture susceptibility - Potential rutting - Implementation costs - Life-cycle concerns - Environment concerns of chemical additives
Research Question/Problem/ Need	How do the different WMA technologies affect materials, mix design, mechanical performance, environmental impact, and cost when compared to HMA.

Important Figures	Figure 1 
VOCAB: (w/definition)	**Foaming Process** – method of producing WMA by injecting water into hot bitumen so it forms foam, which temporarily reduces viscosity **Zeolite** – a mineral with tiny pores that hold water **Anti-stripping Agents (ASA)** – chemicals added to asphalt to improve resistance to moisture damage
Cited references to follow up on	https://etd.ohiolink.edu/acprod/odb_etd/ws/send_file/send?accession=ohiou1224252979&disposition=inline
Follow up Questions	How does this change for even higher zeolite filler?

Article #19 Notes: Performance assessment of warm mix asphalt (WMA) pavements

Article notes should be on separate sheets

Source Title	OhioLINK
Source citation (APA Format)	Al-Rawashdeh, A. S. (2008). *Performance assessment of warm mix asphalt (WMA) pavements* (Master's thesis, Ohio University). OhioLINK Electronic Theses and Dissertations Center. http://rave.ohiolink.edu/etdc/view?acc_num=ohiou1224252979
Original URL	https://etd.ohiolink.edu/acprod/odb_etd/ws/send_file/send?accession=ohiou1224252979&disposition=inline
Source type	Master's thesis
Keywords	Warm mix asphalt Hot mix asphalt Evotherm Aspha-min Sasobit Poisson's ratio Tensile strength
#Tags	#WMA
Summary of key points + notes (include methodology)	The purpose is to evaluate WMA performance vs. HMA. It focuses on mechanical properties, field performance, and structural response by combining laboratory testing, field sections, and Accelerated Pavement Load Facility (APLF) testing. They studied three viscosity-reduction techniques: evotherm (chemical additive/emulsion that improves coating and workability), aspha-min (zeolite releasing water to foam binder), and sasobit (Fischer-Tropsch wax lowering binder viscosity). Methodology: - Laboratory testing for material properties

- Used cylindrical samples of 150 mm diameter and 38-50 mm height; tested at 0, 10, -20 ºC
- Indirect tensile test; for tensile strength, creep compliance, Poisson's ratio
- Used AASHTO/ASTM T 322-03 procedures
- Used to assess low-temperature cracking, fatigue potential, and mixture stiffness

- Field testing through WAY-30 instrumented pavement
  - Used strain gauges (under Fatigue Resistance Layer – FRL)
  - LVDTs (surface and deep) for subgrade deflection
  - Pressure cells at subgrade surface
  - Loading: Controlled vehicle load at 5 mph, falling weight deflectometer (FWD)
  - Measured maximum longitudinal tensile strength + subgrade deflection
- Field Testing through SR-541 (non instrumented)
  - Pavement structure:
  - thin HMA surface + WMA top layer made w/ evotherm/aspha-min/sasobit
  - Control HMA section
  - Used dynamic cone penetrometer (DCP) to estimate CBR and resilient modulus
  - Used FWD
  - Core extraction at construction, 3 months, 1 year, and around 20 months
  - Measured air void ratio and indirect tensile strength over time
- Accelerate Pavement Load Facility (APLF)
  - Repeated wheel loading; comparing 0 vs. 10,000 passes)
  - Temperatures of 40, 70, 104 ºC
  - Strain gauges under FRL
  - Pressure cells in base
  - Subgrade deflection sensors
  - Goal: to compare short-term vs accumulated damage + validate field observations under controlled load

Findings

- Mechanical properties (lab)

	○ Evotherm: behavior closest to control HMA in strength and creep ○ Aspha-min: softest mix at low temperatures, meaning best resistance to thermal cracking ○ Sasobit: slightly lower tensile strength but reduced rutting tendency - Field and APLF Performance ○ WMA pavements showed comparable structural response to HMA (similar tensile strains and subgrade deflections) ○ No early-age performance penalty observed - Air voids and aging: WMA achieved lower/comparable air voids over time; reduced binder aging due to lower production temperature WMA performs as well as conventional HMA structurally in the short/medium term. Different WMA technologies offer different advantages: evotherm is closest to HMA, aspha-min has low-temperature cracking resistance, sasobit has better rutting control. Overall, WMA is viable for perpetual pavements, with added environmental and energy benefits.
Research Question/Problem/ Need	Warm mix asphalt lowers production temperatures and environmental impacts, but its mechanical and structural performance when compared to conventional HMA is not fully established; this research examines whether WMA provides comparable pavement strength, durability, and response under traffic and temperature variations.
Important Figures	Figure 3.11

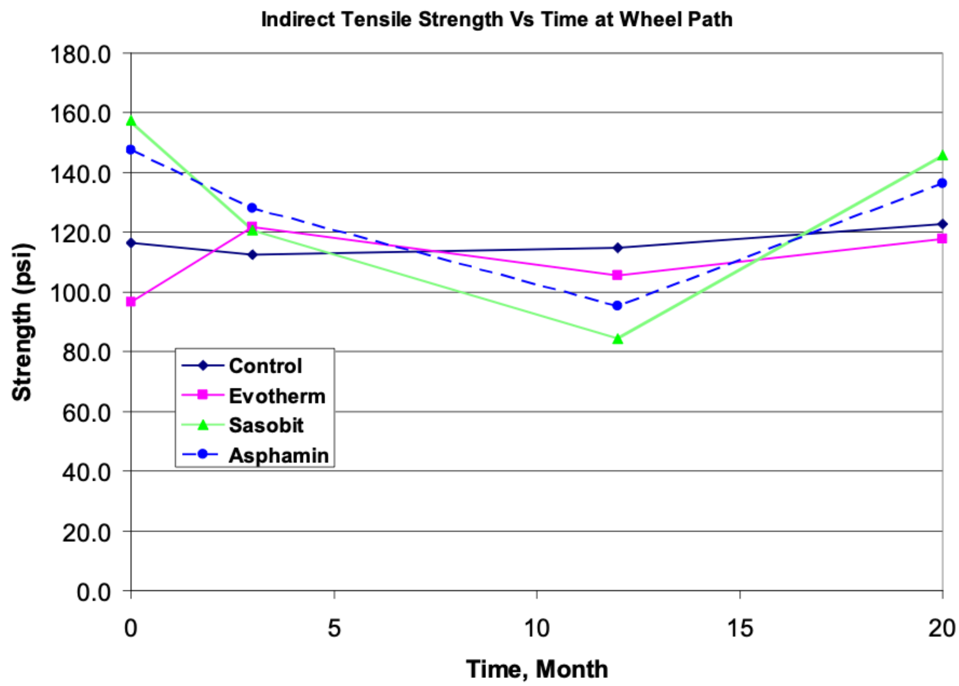
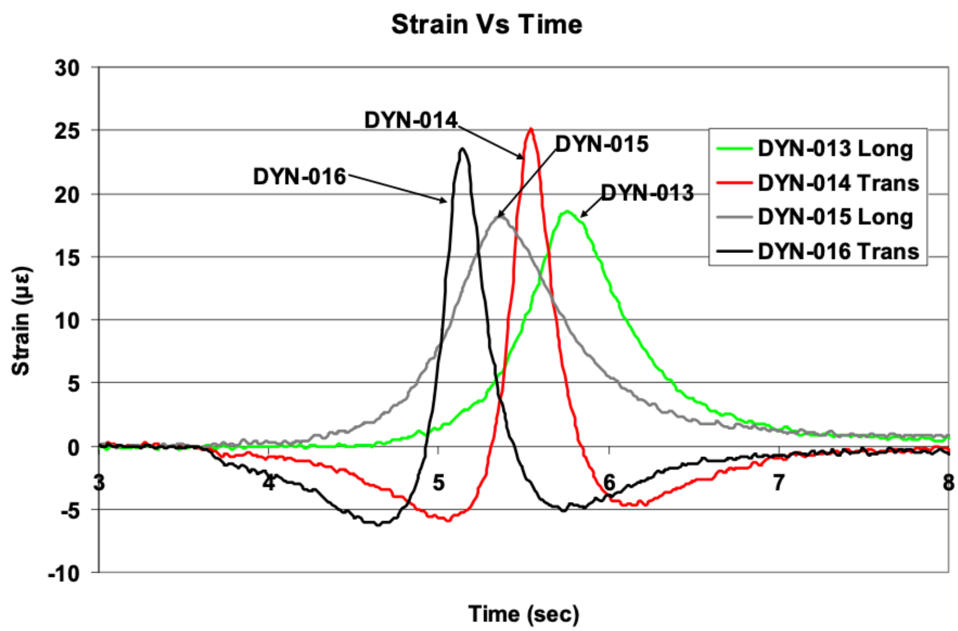


Figure 5.6



VOCAB: (w/definition)	**Fatigue Resistance Layer (FRL)** – asphalt layer designed to resist fatigue cracking **Subgrade Deflection** – vertical movement of the soil foundation under load **Dynamic Cone Penetrometer (DCP)** – field test used to estimate base and subgrade stiffness

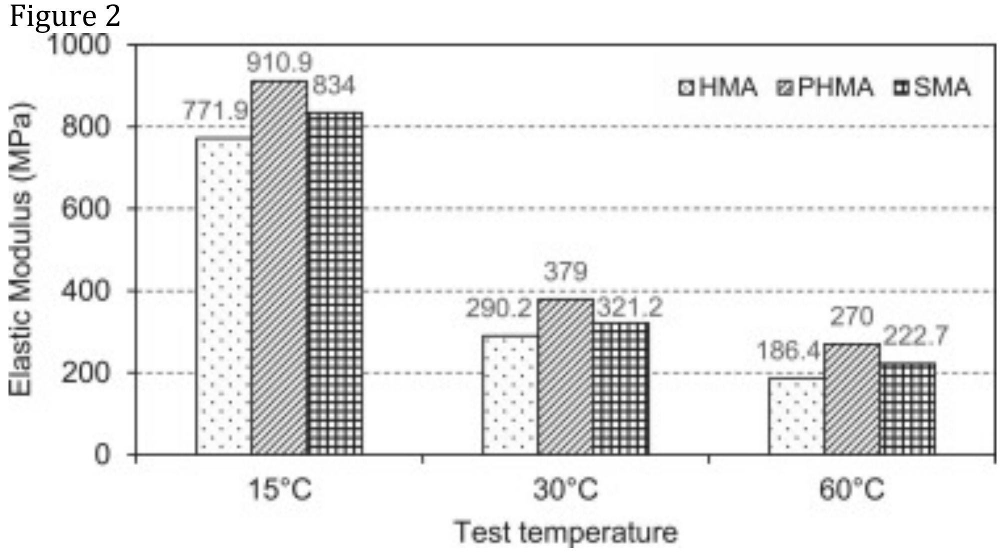
Cited references to follow up on	AASHTO. (2000). *Standard method of test for bulk dpecific gravity of compacted asphalt mixtures using saturated surface-dry specimens*. American Association of State Highway and Transportation Officials. Washington, D.C. AASHTO Designation: T 166-00.
Follow up Questions	How consistent are laboratory performance results with field and APLF measurements for WMA? How does reduced production temperature influence air void content and long-term compaction of WMA?

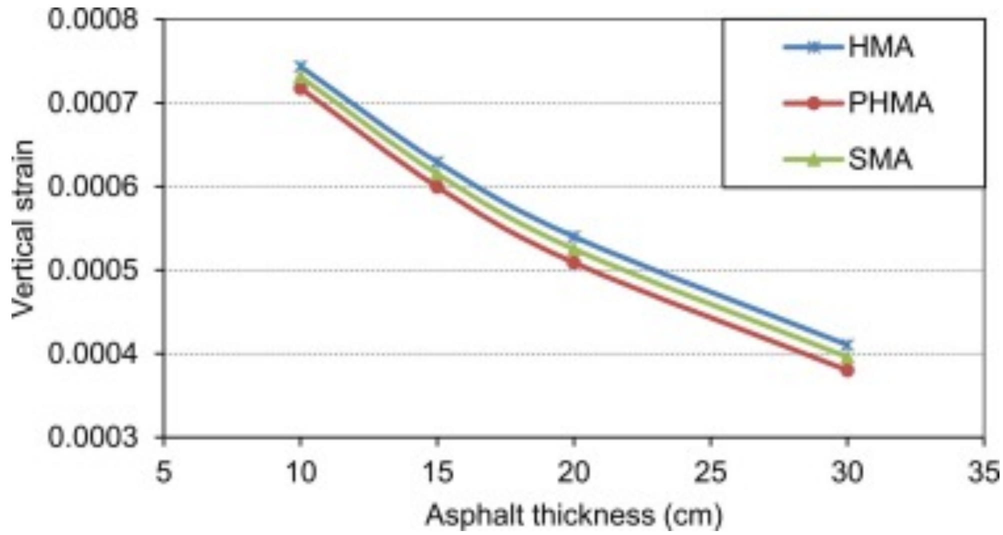
Article #20 Notes: Experimental study on the resistance of asphalt mixtures to permanent deformation and its relation to mechanical behavior of pavement structures

Article notes should be on separate sheets

Source Title	Science Direct
Source citation (APA Format)	Do, T. C., Nguyen, T. H., & Nguyen, V. L. (2025). Experimental study on the resistance of asphalt mixtures to permanent deformation and its relation to mechanical behavior of pavement structures. *Case Studies in Construction Materials*, *22*, e04248. https://doi.org/10.1016/j.cscm.2025.e04248
Original URL	https://www.sciencedirect.com/science/article/pii/S2214509525000476?via%3Dihub
Source type	Journal Article
Keywords	Asphalt mixtures Modified binder Elastic modulus Pavement response Compressive strain Rutting life
#Tags	#WMA
Summary of key points + notes (include methodology)	Permanent deformation (rutting) is a major failure mode in flexible pavements. Elastic modulus strongly controls rutting resistance; higher modulus means lower strains and longer rutting life. Three mixtures were studied: PHMA (polymer hot mix asphalt), SMA, HMA. Maximum tensile stain in the asphalt layer occurred about 10 cm below the surface, suggesting traditional fatigue assumptions may not always apply. Vertical compressive strain on the top of the subgrade is the key indicator for rutting performance. Rutting life increases with higher asphalt thickness, higher subgrade modulus, and decreases sharply with higher contact pressure. When contact pressure is less than 690 kPa, rutting life increases significantly for all mixes. Pavements with PHMA showed ~10-30% longer rutting life than SMA and HMA depending on conditions. Modified binders and optimized gradation improve high-

	temperature performance. Temperature has a strong negative effect on elastic modulus.
	Methodology:
	- HMA, PHMA, SMA, all with the same aggregate source
	- Static modulus test on compacted specimens 100 mm x 100 mm at 15, 30, 60 ºC, constant stress of 0.5 MPa; used to determine elastic modulus of each mixture
	- Analyzed mechanistic pavement using KENLAYER (multi-layer elastic theory) software.
	    o Pavement structure analyzed under variations of asphalt thickness (100-300mm), contact pressure (345-1380 kPa), subgrade modulus (40-70 MPa)
	    o Calculated horizontal tensile strain in AC layer
	    o Vertical compressive strain on top of subgrade
	- Used asphalt institute rutting model; rutting life based on vertical compressive strain at subgrade
	- Compared rutting life across mixes and structural conditions

Research Question/Problem/ Need	How does the elastic modulus of different asphalt mixtures influence pavement mechanical response and resistance to permanent deformation under varying traffic loads, asphalt layer thicknesses, and subgrade conditions?
Important Figures	Figure 2  Figure 4

	
VOCAB: (w/definition)	**Polymer Hot Mix Asphalt (PHMA) –** asphalt mixture using polymer-modified binder to improve high-temperature performance **Static Modulus Test –** lab test used to determine elastic modulus under controlled stress **Multi-Layer Elastic Theory –** analytical approach modeling pavement as stacked elastic layers **KENLAYER –** software program used for mechanistic pavement response analysis **Critical Strain Location –** depth in the pavement where maximum strain occurs
Cited references to follow up on	https://www.sciencedirect.com/science/article/pii/S0950061811006726 https://www.sciencedirect.com/science/article/pii/S2214509524003371 https://www.sciencedirect.com/science/article/pii/S2352146516303490
Follow up Questions	How does temperature-dependent elastic modulus affect rutting life predictions? Would viscoelastic or viscoelastic material models change the predicted critical strain location compared to linear elastic analysis?

Patent #1 Notes: Functional group asphalt modifiers, methods of modifying asphalt, asphalt compositions and methods of making

Article notes should be on separate sheets

Source Title	Google Patents
Source citation (APA Format)	Naidoo, P., & Keating, V. P. (Inventors). (2019). *Functional group asphalt modifiers, methods of modifying asphalt, asphalt compositions and methods of making* (U.S. Patent No. 10,479,892 B2). U.S. Patent and Trademark Office. https://patents.google.com/patent/US10479892B2/en.
Original URL	https://patents.google.com/patent/US10479892B2/en?q=(warm+mix+asphalt)&oq=warm+mix+asphalt
Source type	Patent
Keywords	Warm mix asphalt Polyolefin Polymer-modified asphalt Storage stability Ground tire rubber Rheology
#Tags	#WMA
Summary of key points + notes (include methodology)	- Introduces a functional asphalt modifier made of a primary rheology-modifying polymer (polyolefins, elastomers, etc.) and a secondary rheology modifying component (petroleum micro-wax) - Modifier is engineered to disperse uniformly in asphalt at normal mixing temperatures, avoiding separation problems seen w/ conventional polymer/rubber modifiers - Reduces WMA mixing and compaction temperatures by 30-70 ºF - Lowers emissions and energy consumption - Improves workability and compaction - Improves high-temperature rutting resistance while maintaining low-temperature cracking performance

- Can replace or supplement SBS and stabilize ground tire rubber in asphalt binders
- Solves phase separation by forming composite particles before addition to asphalt and using wax as a carrier that melts first, enabling polymer dispersion
- Addresses industry challenges of high cost and supply issues of SBS, poor stability of GTR-modified binders, compaction difficulty with stiff binders and SMA/OGFC mixes
- Demonstrated compatibility with PG grading, MSCR, DSR, BBR, and cigar tube separation tests

Methodology

- Additives are prepared by having the polymer melt-blended with a binder component, which is then solidified into particles typically less than 420 µm
- Prepared particles are added directly to petroleum asphalt during mixing
- Once heated, the wax melts first, and polymers disperse uniformly into the binder resulting in a homogenous, stable modified asphalt
- Performance evaluation using:
    - Cigar tube separation test (ASTM D7173); improved storage stability
    - Dynamic Shear Rheometer (DSR); increased high-temperature stiffness
    - Multiple Stress Creep Recovery (MSCR); improved rutting resistance
    - Bending Beam Rheometer (BBR); acceptable low-temperature performance
- Field and project data show target PG grades achieved with good density and air-void control

Research Question/Problem/ Need

How can asphalt binders be modified using polymer-wax composite additives to improve storage stability, workability, and high-temperature performance while enabling lower production and compaction temperatures?

Important Figures

Table 1

	Method	Base Asphalt	Base Asphalt plus 4% Additive A	Base Asphalt plus 4% Additive B
Continuous PG Grade		68.4-24.2	78.9-23.03	75.3-23.69
Rotational Visco. at 270 F., cps	TP 48			
Rotational Visco. at 300 F., cps	TP 48			
Rotational Voisc. at 135 C., cps	TP 48	0.56	1280.00	1030
Dynamic Shear Rheometer:	T315			
Temperature Pass, C.		67.00	76.00	70.00

Phase Angle			68.10	82.00
G* at 10 rad/sec, kPa.			1.62	1.76
G*/sin delta at 10 rad/sec., kPa.		1.27	1.74	1.77
Temperarure Fail, C.		69.00	82.00	76.00
Phase Angle			64.80	83.80
G* at 10 rad/sec, kPa.			1.00	0.93
G*/sin delta at 10 rad/sec., kPa.			1.10	0.94
Pass/Fail, Temp. C.			83.10	75.30
RTFO Residue Tests:				
Mass Loss, %	T240	0.06	0.27	−0.26
Dynamic Shear Rheometer	T315	2.62		
Temperature Pass, C.		68.40	76.00	70.00
Phase Angle			73.30	76.80
G* at 10 rad/sec, kPa.			2.83	4.76
G*/sin delta at 10 rad/sec., kPa.			2.95	4.83
Tempersture Fail, C.			82.00	76.00
Phase Angle			74.00	79.20
G* at 10 rad/sec, kPa.			1.55	2.35
G*/sin delta at 10 rad/sec., kPa.			1.60	2.39
Temperature Pass/Fail, C.			78.90	76.70
PAV Residue Tests:				
Dynamic Shear Rheometer	T315			
Temperature, C.		25.00	28.00	28.00
Phase Angle			43.00	41.90
G* at 10 rad/sec, kPa.			2590.00	3860.00
G*/sin delta at 10 rad/sec., kPa.			1770.00	2580.00
Bending Beam Rheometer	T313			
Temperature Pass, C.		−12.00	−12.00	−12.00
Stiffness, 60 s, Mpa		104.00	142.00	147.00
M-value, 60 s		0.35	0.31	0.31
Temperature Fail, C.			−18.00	−18.00
Stiffness, 60 s, Mpa			283.00	300.00
M-value, 60 s			0.27	0.27

Additional Dynamic Shear Rheometer (DSR) Data Demonstrating Effectiveness of PP Compounds in High Temperature Performance Grading

Sample Reference	Composition, % m/m of Additive	G*	G*/Sind	Phase Angle Degrees	Test Temperature, C.
Base Valero PG 67-22					
3% SB2 in V67-22	85% PP (stream 1) plus 15% PE Wax	1.00 0.73	1.01 0.75	84.2 75.8	67 82
4% SB2 in V67-22	85% PP (stream1) plus 15% PE Wax	1.28 1.42	1.31 1.49	76.5 72.0	76 82
6% SB2 in V67-22	85% PP (stream1) plus 15% PE Wax	1.14	1.26	64.5	88
3% SB3 in V67-22	85% PP (stream 2) plus 15% PE Wax	0.84	0.85	82.5	76
3% SB4 in V67-22	85% PP (stream 2) plus PE Wax	1.64 0.81	1.66 0.82	81.3 84.4	70 76
3% SB5 in V67-22	100% PP (Stream 2)	1.66 0.87	1.67 0.88	83.0 84.0	70 76
3% SB6 in V67-22	42.5% PP Wax Stream 1) plus 42.5% PP Wax (stream 2) plus 15% PE Wax	1.76 0.97 1.95	1.78 0.98 1.97	82.6 82.5 81.4	70 76 70

VOCAB: (w/definition)

Polyolefin – polymer used to increase stiffness
Storage Stability – ability of modified asphalt to resist phase separation during storage
Rheology – flow and deformation behavior of asphalt binder
Multiple Stress Creep Recovery – test evaluating rutting resistance and elastic recovery
Ground Tire Rubber (GTR) – recycled rubber from tires used as an asphalt modifier

Cited references to follow up on	https://patents.google.com/patent/US3853800A/en?q=(warm+mix+asphalt)&oq=warm+mix+asphalt https://patents.google.com/patent/US5708062A/en?q=(warm+mix+asphalt)&oq=warm+mix+asphalt
Follow up Questions	How does particle size affect the properties? Can PET-based/recycled plastic polymers replace polyolefins?

Patent #2 Notes: Bitumen compositions

Article notes should be on separate sheets

Source Title	Google Patents
Source citation (APA Format)	Maillet, J., Komornicki, J., Miyaki, Y., Mohri, H., Tada, S., Perret, P., Gazeau, S., Brule, B., & Shiojiri, K. (Inventors). (1998). *Bitumen compositions* (U.S. Patent No. 5,708,062 A). U.S. Patent and Trademark Office. https://patents.google.com/patent/US5708062A/en
Original URL	https://patents.google.com/patent/US5708062A/en?q=(warm+mix+asphalt)&oq=warm+mix+asphalt
Source type	Patent
Keywords	Bitumen
#Tags	#WMA
Summary of key points + notes (include methodology)	This patent is on an improved bitumen composition. It is made of 100 parts bitumen, 0.1-10 parts of a copolymer of an alpha-olefin, of an unsaturated epoxide and of an ester of unsaturated carboxylic acid, 0.1-10 parts of a copolymer of an alpha-olefin and of an ester of unsaturated carboxylic acid, 0-10 parts of a thermoplastic elastomer, 0-10 parts of a polymer reactive with the first 0.1-10 parts, and 0-10 parts of an ethylene/vinyl acetate copolymer. The bitumen made from this is stable when stored and resists rutting. In specific, this describes bitumen modified with polymers which have glycidyl methacrylate groups. The bitumen's viscosity should be between 10 and 20,000 poises, which it preferably being between 300 and 5,000.
Research Question/Problem/ Need	There is a need for a bitumen that is stable when stored and can resist rutting.
Important Figures	Table 3

	Example				raw	Comparative Example				
	3	4	5	6	bitumen	1	2	3	4	5
Initial values										
Softening point (°C.)	60	76	69	75	50	61	54	81	97	72
Needle penetration (1/10 nm)	39	37	37	39	51	36	62	37	34	40
Extension (15° C.) (cm)	73	66	52	59	120+	54	13	62	71	103
Viscosity at 135° (cP)	2160	1940	3020	1980	360	1440	1100	2170	5000	2200
Dynamic stability (times/mm)	9500	9100	9300	10500	770	3200	—	7500	—	6200
After 3 days at 170° C., high portion										
Softening point (°C.)	95	95	100	102	—	93	56	—	100+	87
Needle penetration (1/10 mm)	55	51	45	59	—	51	62	—	76	93
Extension (15° C.) (cm)	85	75	70	79	—	100+	15	—	100+	100+
After 3 days at 170° C., low portion										
Softening point (°C.)	70	71	75	60	—	50	51	—	65	70
Needle penetration (1/10 mm)	36	34	40	35	—	30	61	—	25	21
Extension (15° C.) (cm)	40	47	46	359	—	25	13	—	10	0

VOCAB: (w/definition)	**Copolymer** – a polymer made from two or more different types of monomer units chemically bonded in the same chain **Epoxide** – a highly reactive, three-membered cyclic ether containing two carbons and one oxygen **Alpha-olefin** – an unsaturated hydrocarbon with a double bond at the first (alpha) carbon of its chain **Ester** – an organic compound made by replacing the hydrogen of an acid by an alkyl or other organic group **Thermoplastic Elastometer** – a versatile polymer that acts like rubber but processes like plastic
Cited references to follow up on	https://patents.google.com/patent/JPS61215658A/en?q=(warm+mix+asphalt)&oq=warm+mix+asphalt
Follow up Questions	What are the production costs? What are the effects on the environment?