UNCOVERING THE SCIENCE OF PENETRATING PRIME EMULSIONS

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7th International Symposium on Asphalt Emulsion Technology
October 26-28, 2021 | Virtual

AEMA ASPHALT EMULSION MANUFACTURERS ASSOCIATION | ibef International Bitumen Emulsion Federation

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BUILDING A NEW LEADER IN SPECIALTY SURFACTANTS

OVERVIEW

- INTRODUCTION TO ASPHALT PRIME COATS & KEY INDUSTRY CHALLENGES
- THE SCIENCE BEHIND PRIME COATS
- PERFORMANCE AND RELIABILITY TESTING AND RESULTS
- THE FUTURE OF ASPHALT PRIME COATS
- SUMMARY

INTRODUCTION TO ASPHALT PRIME COATS & KEY INDUSTRY CHALLENGES

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WHAT IS A PRIME COAT?

A prime coat is:

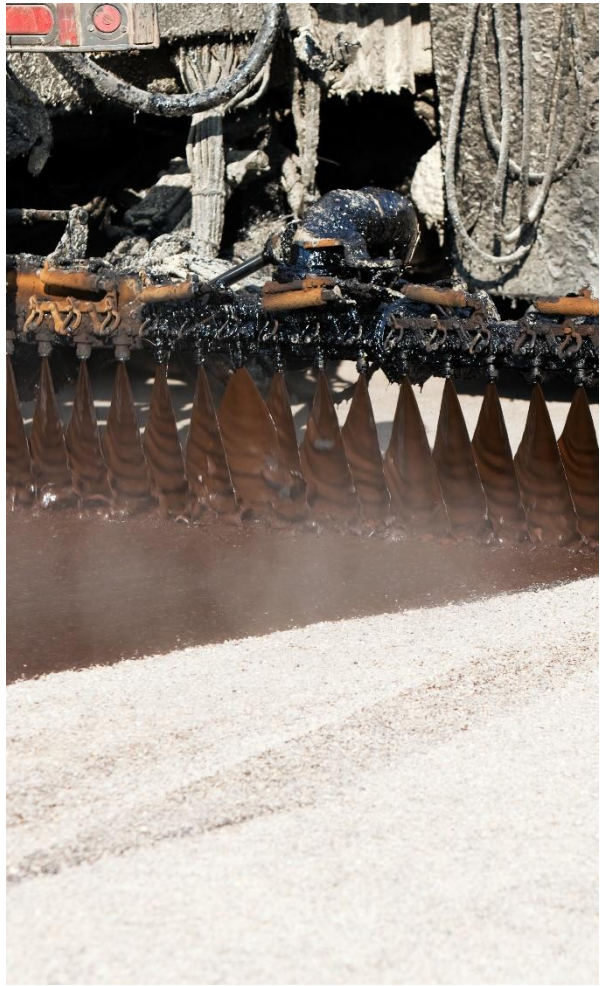
- An application of low viscosity binder to a granular base surface, or
- Mixing of low viscosity binder into the upper portion of a granular base in preparation for an initial asphalt layer or chip seal

Prime coats are used to:

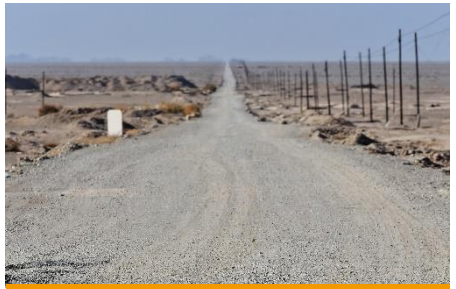
- Toughen the surface for the next pavement layer
- Promote adhesion between the granular base and the next pavement layer

Types of Prime Coats:

- Cutback – asphalt, solvent
- Emulsion (Anionic or Cationic) – asphalt, emulsifier, solvent, water

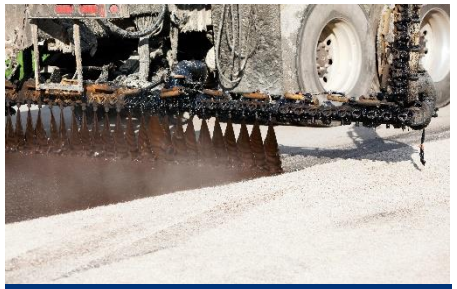


PRIME COAT APPLICATION



PREPARATION

- With dense granular bases or stabilized bases, the surface may need to be prepared



SPRAY APPLICATION

- Diluted prime coat material is sprayed
- Must avoid potential rainy days to prevent runoff prior to complete cure

SAND APPLICATION

- After 24 hours, sand is scattered onto the bed to absorb excess prime
- After absorption, the blotter sand must be removed

COMPLETE CURING

- Typically 3-5 days or longer

FINAL PAVING COURSE

- Surface is now ready for HMA or chip seal treatment

PROPERTIES OF HIGH-PERFORMANCE PRIME COATS

Emulsion absorbs quickly

- Minimizes traffic pickup
- Eliminates the need for sanding

Emulsion penetrates sufficiently deep

The primed road is ready to be paved in a short period of time

PRIME COAT CHALLENGES

FOR EMULSION PRODUCERS:

- Emulsion-based prime coats may not perform as well as cutbacks
- Anionic prime coat emulsions tend to outperform cationic prime coat emulsions
- Solvents which usually contain volatile organic compounds (VOCs) are required:
  - Increasing formulation costs
  - Raising worker safety concerns

FOR PAVING CONTRACTORS:

- Increased construction time required:
  - To spread sand on the surface
  - For a full cure which typically takes 3-5 days or longer
  - To avoid unfavorable weather conditions
- Poor penetration leads to tracking away of prime coat and vehicular damage liability

FOR AGENCIES:

- Increased construction time results in slower return to traffic and added motorist delays
- Prime coats containing solvents increase the risk of community / citizen odor complaints and safety concerns
- Poor application lessens pavement durability, shortening pavement life and increasing maintenance costs
- No effective method to accurately evaluate the reliability of prime coats before applying on the road

SO HOW DO WE SOLVE THESE CHALLENGES?

THE SCIENCE BEHIND PRIME COATS

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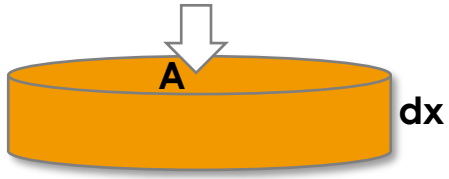
UNDERSTANDING IMPREGNATION PHENOMENON

- Impregnation is the flow of a liquid through a porous material
- Darcy's law explains the dependence of the volumetric flux to the material permeability (k), to the fluid viscosity (η) and to pressure difference (dp): $Q = \frac{k}{\eta} A \frac{dp}{dx}$



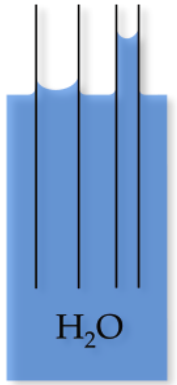
- Two main hypothesis:
  - Laminar flow
  - No interactions between material and fluid
- Flux is ruled by the biggest pore size
  - Small particles and/or deformable particles

- In our case, the fluid is an emulsion
- Viscosity is ruled by continuous phase viscosity, maximum volume fraction and volumetric fraction
  - Polydispersity, particles shape and diameter
  - Bitumen viscosity, interfacial tension and emulsification parameters

THE ASPHALT PARTICLE IS CARRIED BY THE CONTINUOUS PHASE

UNDERSTANDING IMPREGNATION PHENOMENON

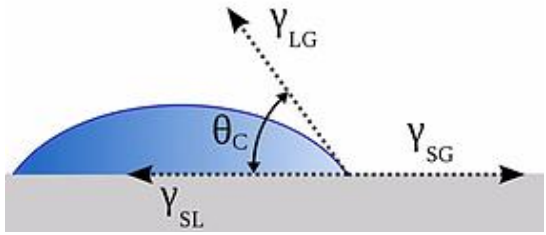
- Capillarity flow in opposition to gravity is one of the most spectacular demonstration of the phenomenon



- Interactions between immiscible liquids, a liquid and a solid or a liquid and a gas explain the phenomenon
- Interfacial tensions rules the capillarity flow

- Young Dupré law shows that the shape of a liquid drop depends on its interactions with the gas and solid

$$\cos\theta_C = \frac{\gamma_{SG} - \gamma_{LS}}{\gamma_{LG}}$$



- A better wetting means that Θc is lower (= better solid/liquid affinity)
- Affinity is ruled by polar interactions, Van Der Waals forces and hydrogen bonds
- Surfactant is also avoiding emulsion breaking

SUMMARY OF THE SCIENCE

CAPILLARY RESTRICTION

- Laplace pressure
- Smaller particle size asphalt emulsion is better
- Deformable particles are better

CONTINUOUS PHASE

- The water carries the asphalt

WETTING

- Surfactant type
  - Surface tension must be sufficiently low
- Surfactant quantity
  - Higher aggregate specific surface area requires more
  - Higher aggregate surface charge requires more

SUBSTRATE DEMANDS

- Granular Base
  - Consistent gradation and density
- High Clay
  - High surface charge
  - High water adsorption
- Sand
  - Low surface charge and high air voids

NOW THAT WE UNDERSTAND THE SCIENCE, HOW DO WE MEASURE RELIABILITY?

PERFORMANCE AND RELIABILITY TESTING AND RESULTS

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PERFORMANCE TESTING – A MEASURE OF RELIABILITY

Illinois DOT Method

- Silica sand of a controlled size
- Add 5% limestone dust
- Add 5% water
- Compact

Emulsion addition

- Fixed emulsion residue
- Add a fixed rate of emulsion

Specification

- Minimum penetration

Strengths

- Uniform aggregate structure
- Adds limestone dust for chemical complexity
- Uniform compression and capillary size

Weaknesses

- Very low surface charge
  - Does not use actual field materials
- Compression is low
- Test soil is moistened facilitating penetration

Overall assessment

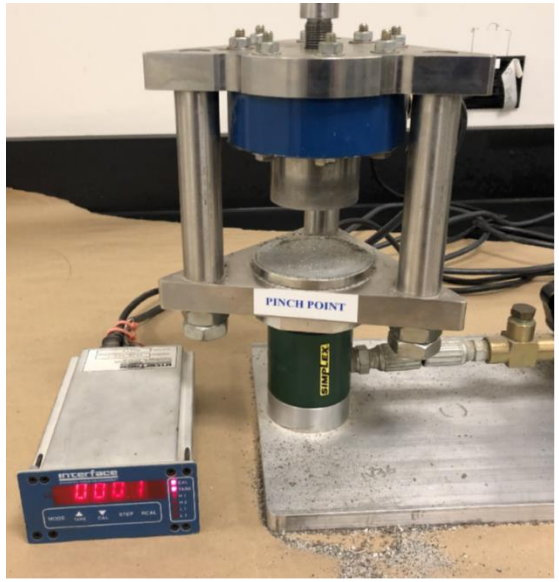
- Silica being relatively easy to penetrate
- Wet soil assists penetration
- Low compression aids penetration

ALMOST ALL EMULSIONS PASS THIS TEST!

PERFORMANCE TEST

Sample Preparation

- Sieved through #8 screen
- 5% water added as lubricant
- Compressed to 100 psi (689 KPa) in a 3 oz pen cup
- Dried at 110 °C overnight
- Cooled to room temperature for testing



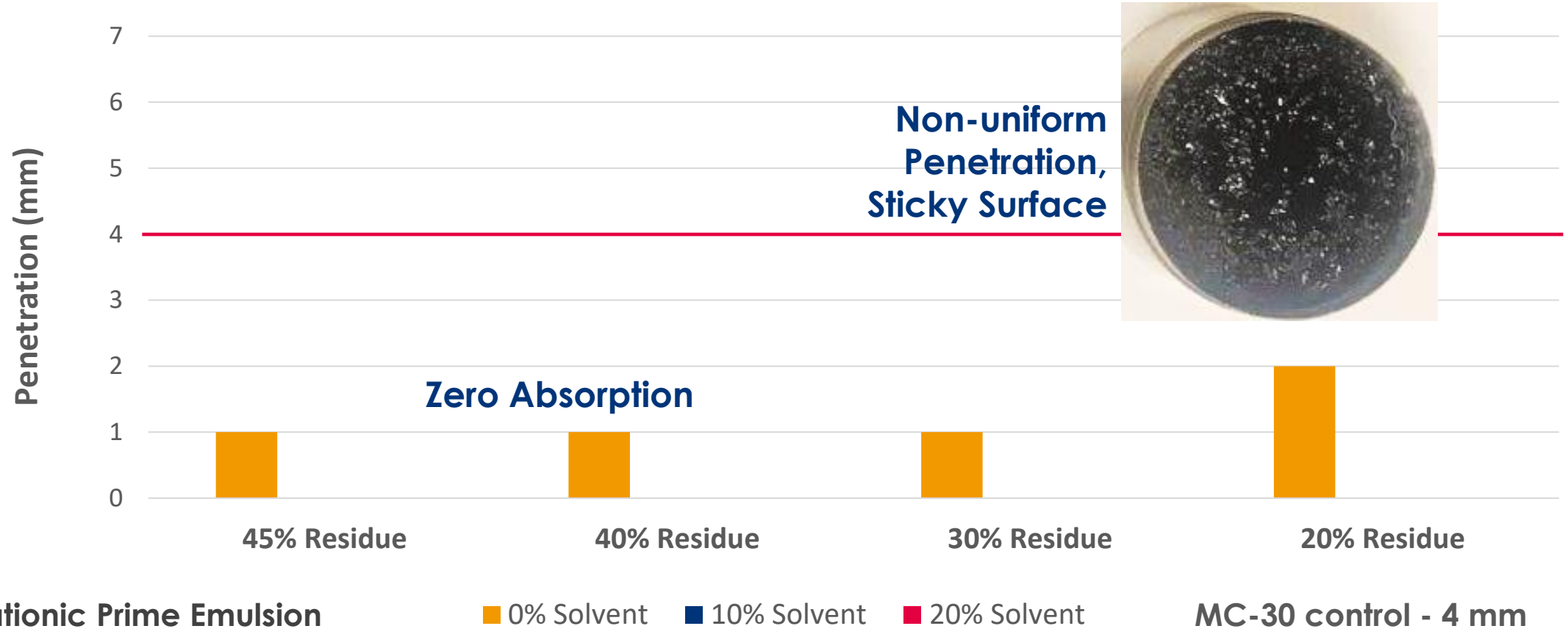
Test Method

- Asphalt emulsion diluted to 40% solids for prime, 5% to 20% for dust control
- Diluted emulsion pre-weighed to apply 1.0 L/m^2
- Emulsion is poured onto the compressed soil quickly and a stopwatch is started
- The emulsion is swirled around to total coverage
- The stopwatch is stopped when all free liquid is absorbed

TYPICAL CATIONIC PRIME COAT EMULSION FORMULATION

- 60 pen asphalt
- Typical emulsifier
- 15% solvent
- 40% residue

EFFECTS OF SOLVENT ADDITION AND EMULSION RESIDUE



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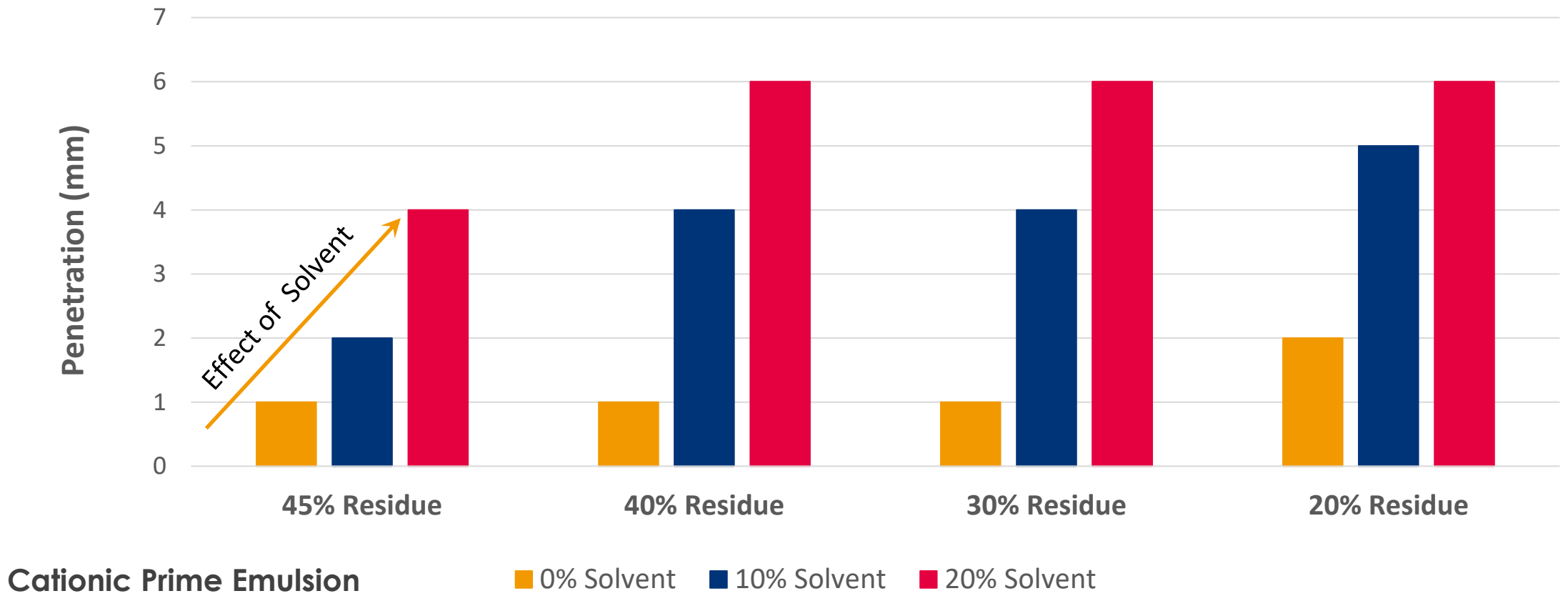
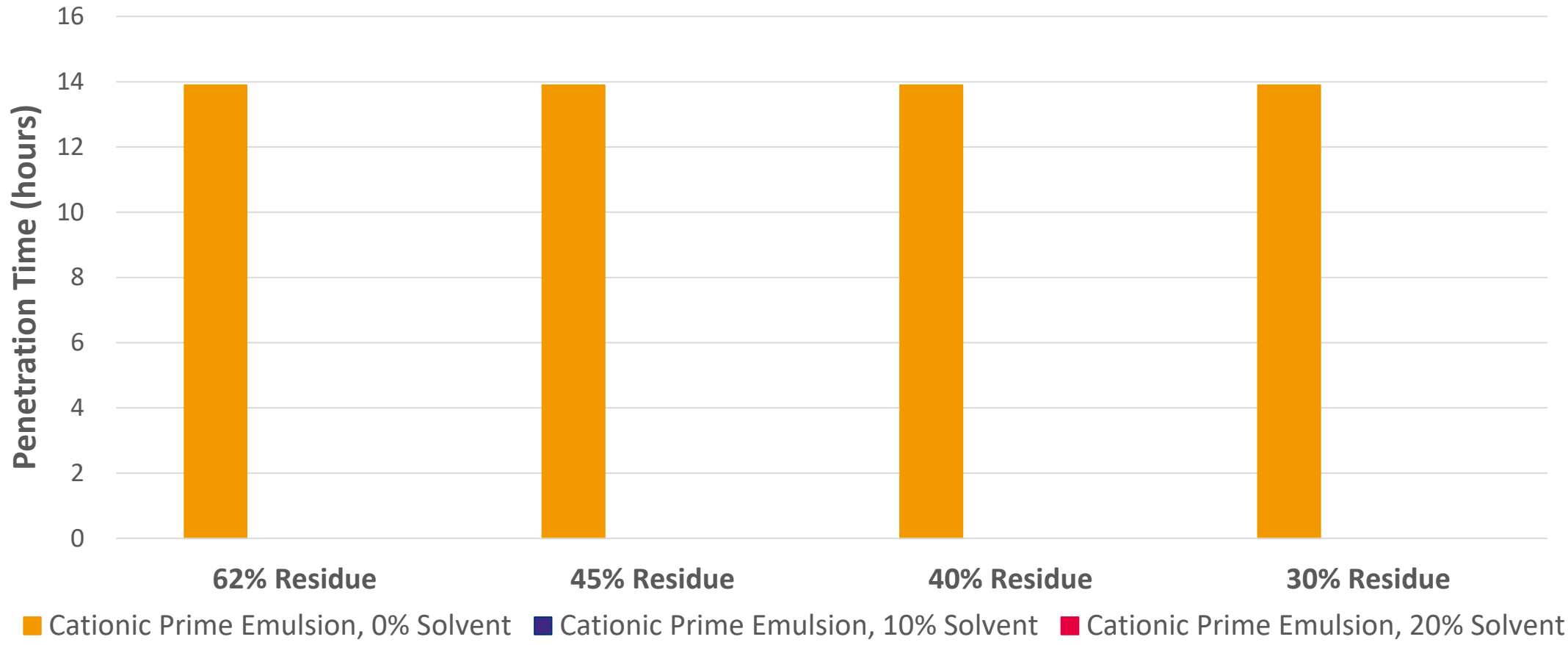
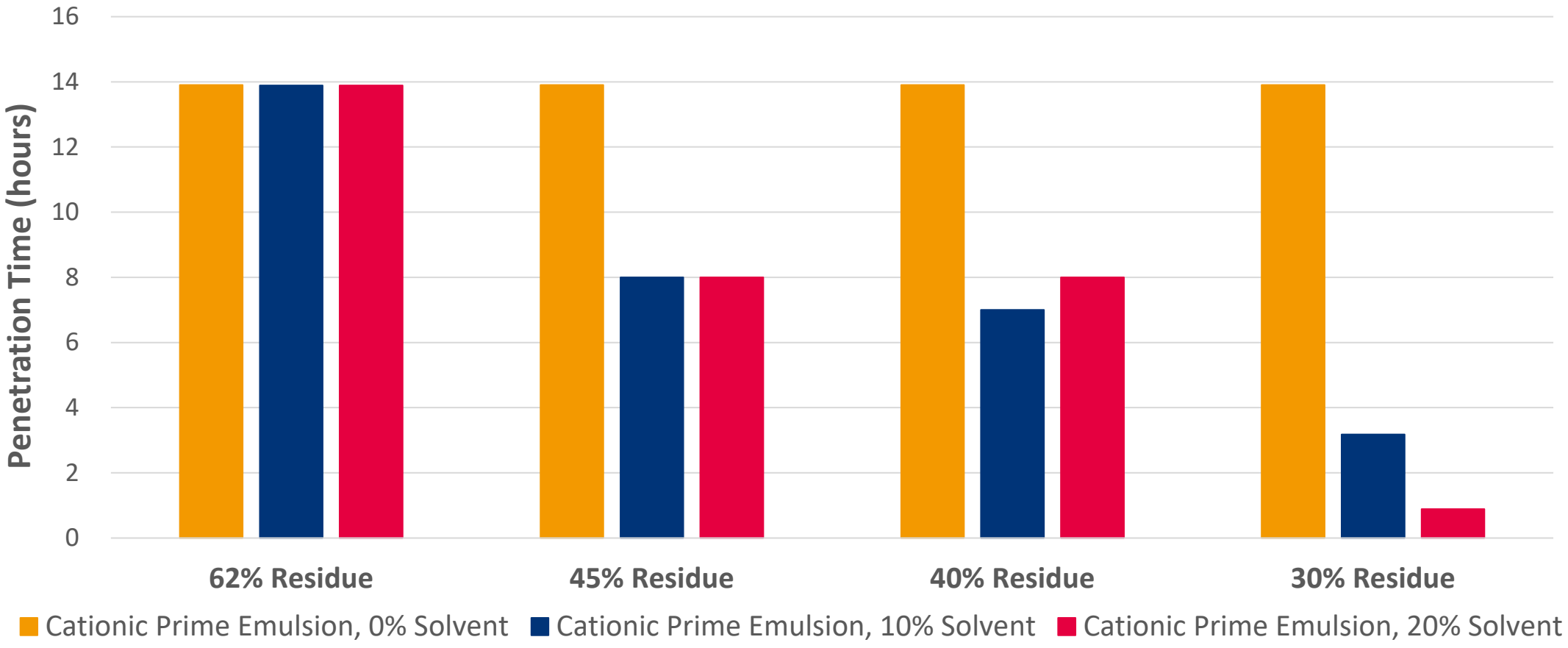


SOLVENT USE INCREASES PENETRATION DEPTH

PENETRATION TIME



PENETRATION TIME



SOLVENT USE ALLOWS FOR QUICKER PENETRATION

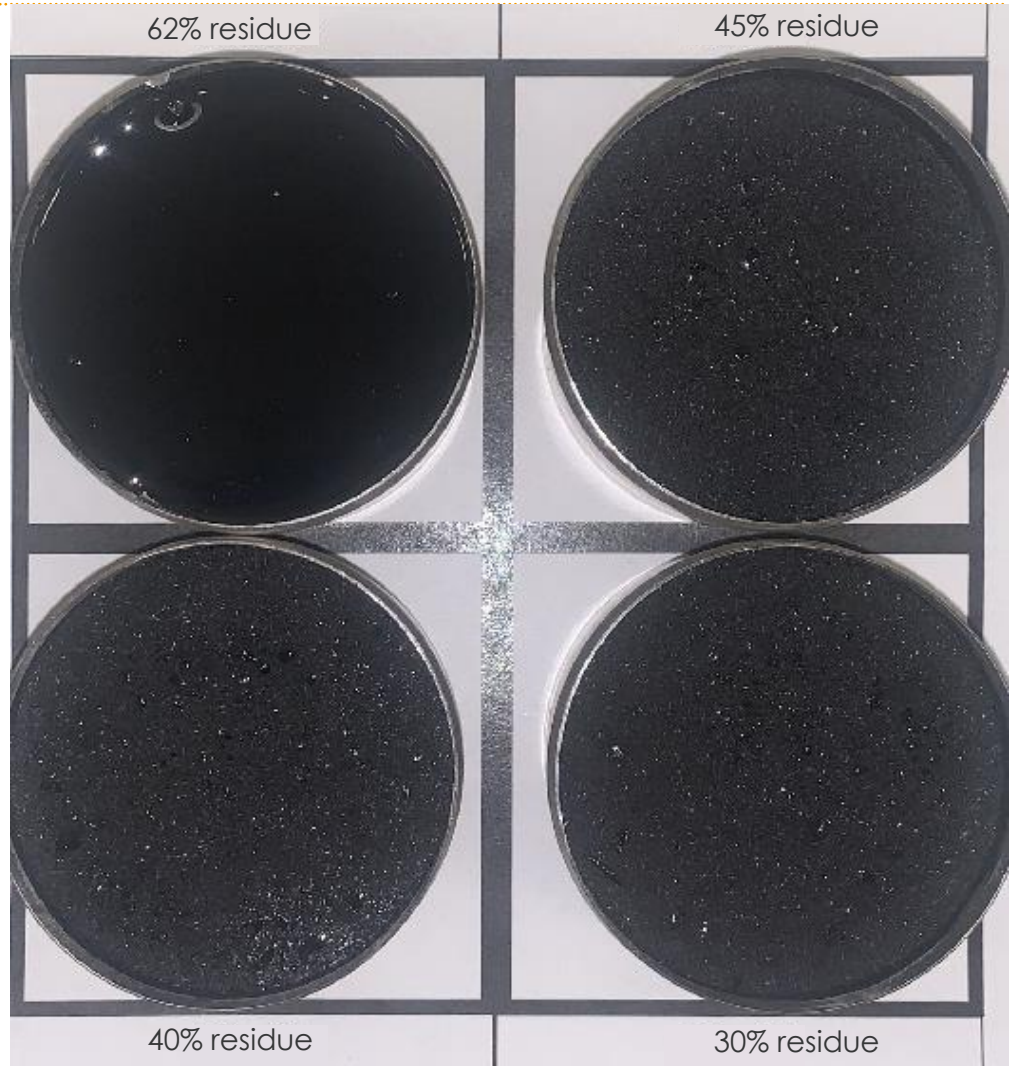
CATIONIC PRIME COAT EMULSION – 10% SOLVENT

62% Residue
- Dark black color and very shiny, extremely tacky
- 2 mm penetration, 8+ hours

45% Residue
- Dark black color, not shiny, very tacky
- 2 mm penetration, 7 hours

40% Residue
- Dark black color, not shiny, very tacky
- 2 mm penetration, 3.2 hours

30% Residue
- Dark black color, not shiny, very tacky
- 4 mm penetration, 2.8 hours



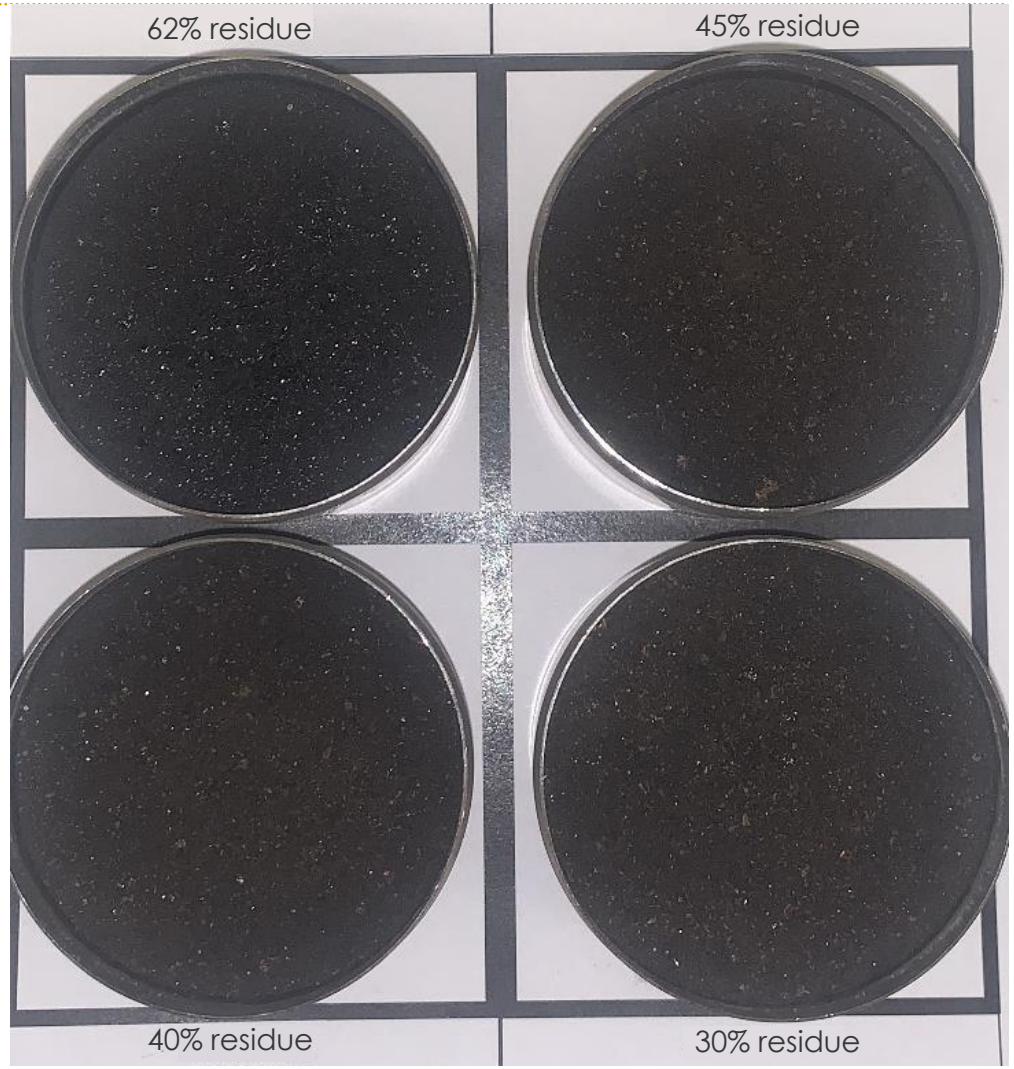
CATIONIC PRIME COAT EMULSION – 20% SOLVENT

62% Residue
- Dark black color, slightly shiny, slightly tacky
- 4 mm penetration, 8+ hours

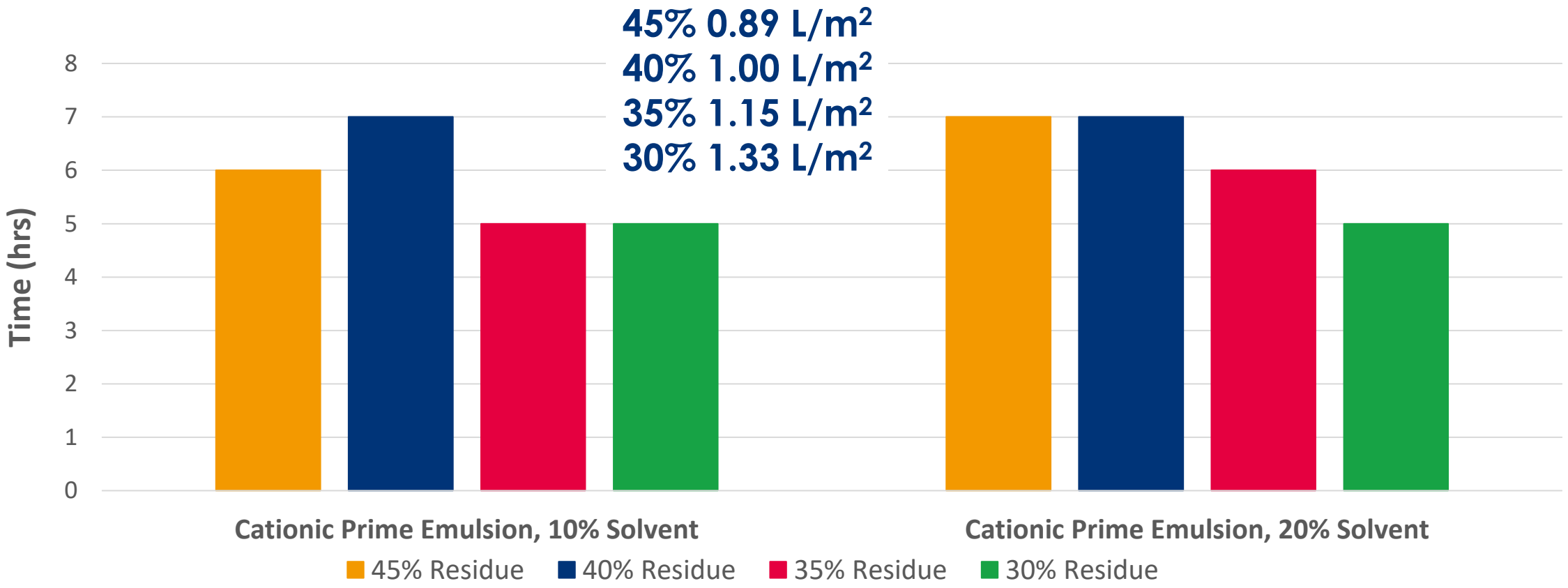
45% Residue
- Dark brown color, not shiny, very slightly tacky
- 4 mm penetration, 8 hours

40% Residue
- Dark brown color, not shiny, very slightly tacky
- 5 mm penetration, 8 hours

30% Residue
- Dark brown color, not shiny, not tacky
- 6 mm penetration, 1 hour

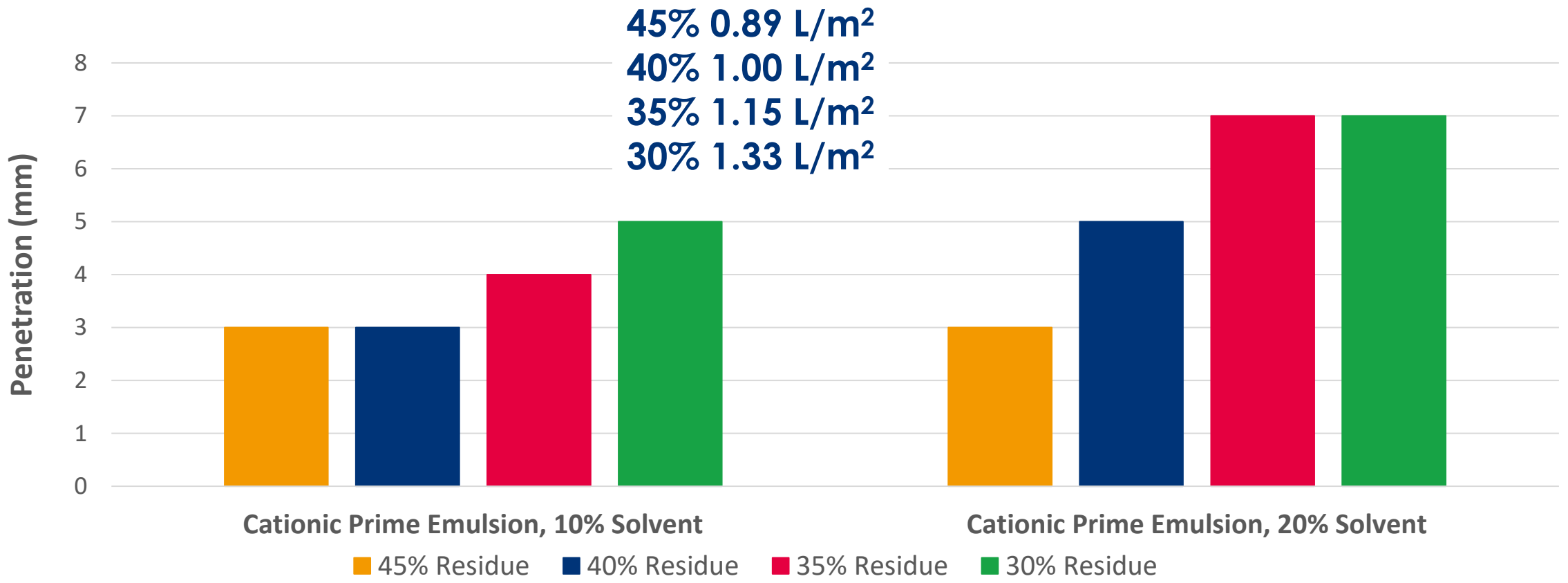


EQUAL ASPHALT CONTENT – PENETRATION TIME



LOWER RESIDUE AND HIGHER APPLICATION RATES PROVIDE SIMILAR PERFORMANCE

EQUAL ASPHALT CONTENT – PENETRATION



LOWER RESIDUE AND HIGHER APPLICATION RATES PROVIDE BETTER PERFORMANCE

THE FUTURE OF ASPHALT PRIME COATS

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NEXT-GENERATION CATIONIC TECHNOLOGY – SOLVENT-FREE APPLICATION

- Solventless formula
- PG 64-22 asphalt, ~60 pen
- 40% residue emulsion
- 1 L/m^2 application rate
- 14 seconds penetration time

NEXT-GENERATION CATIONIC TECHNOLOGY – EASIER & FASTER APPLICATION

Typically adsorbs in seconds

- Minimal traffic delay
- Minimum user risk

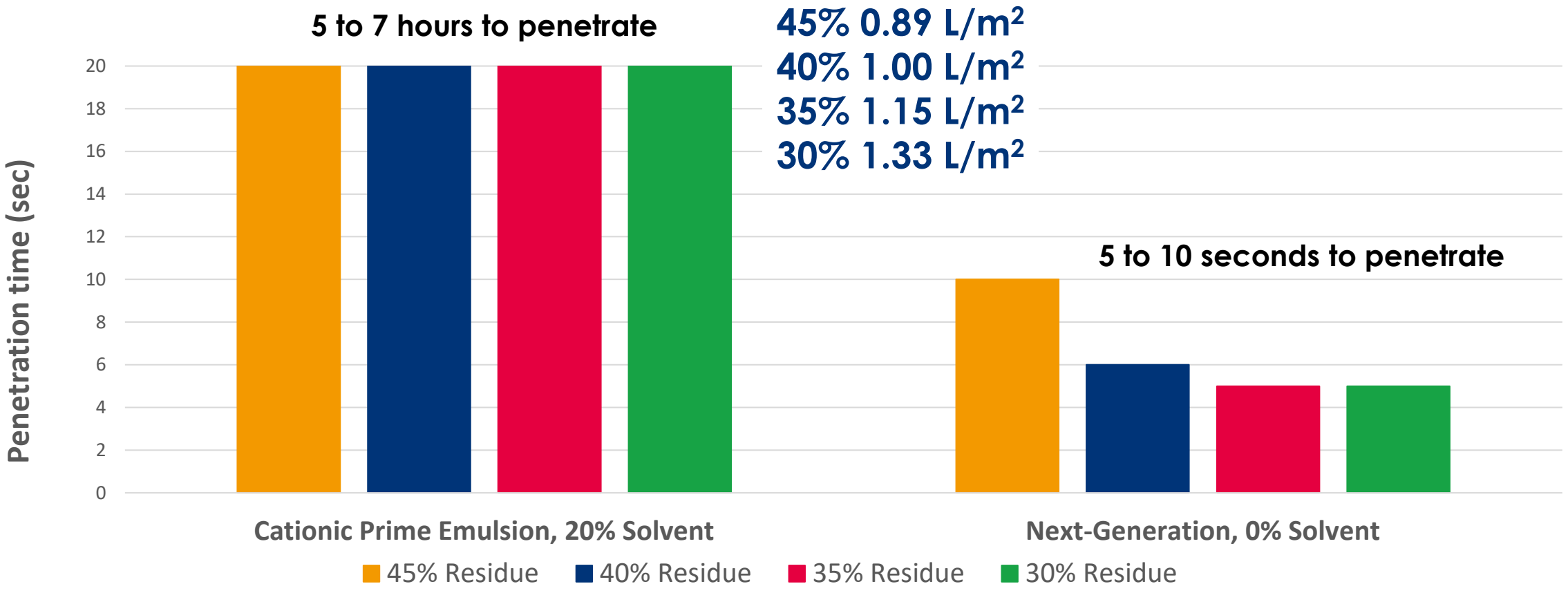
Surface Tack

- Minimal
- Little chance for tire pickup

Toughening

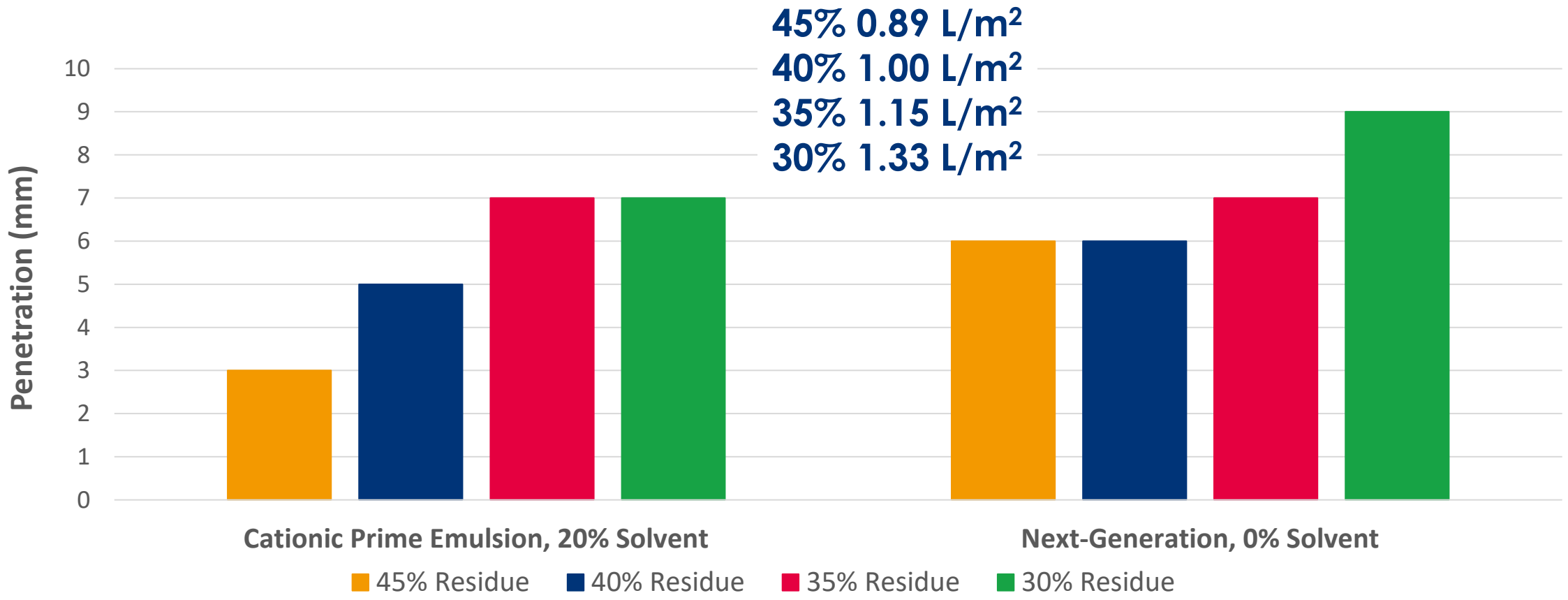
- Surface hardens as soon as water dries
- Potential to pave in as little as 1 hour

EQUAL ASPHALT CONTENT – PENETRATION TIME



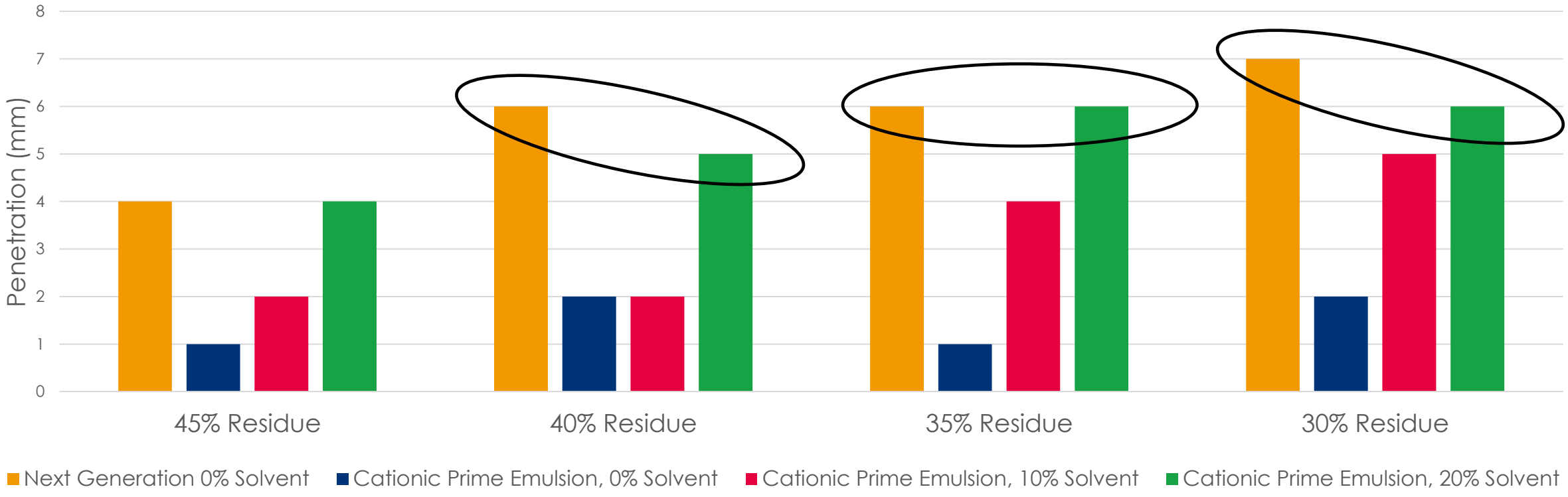
THE EMULSION PENETRATES IN SECONDS NOT HOURS

EQUAL ASPHALT CONTENT – PENETRATION



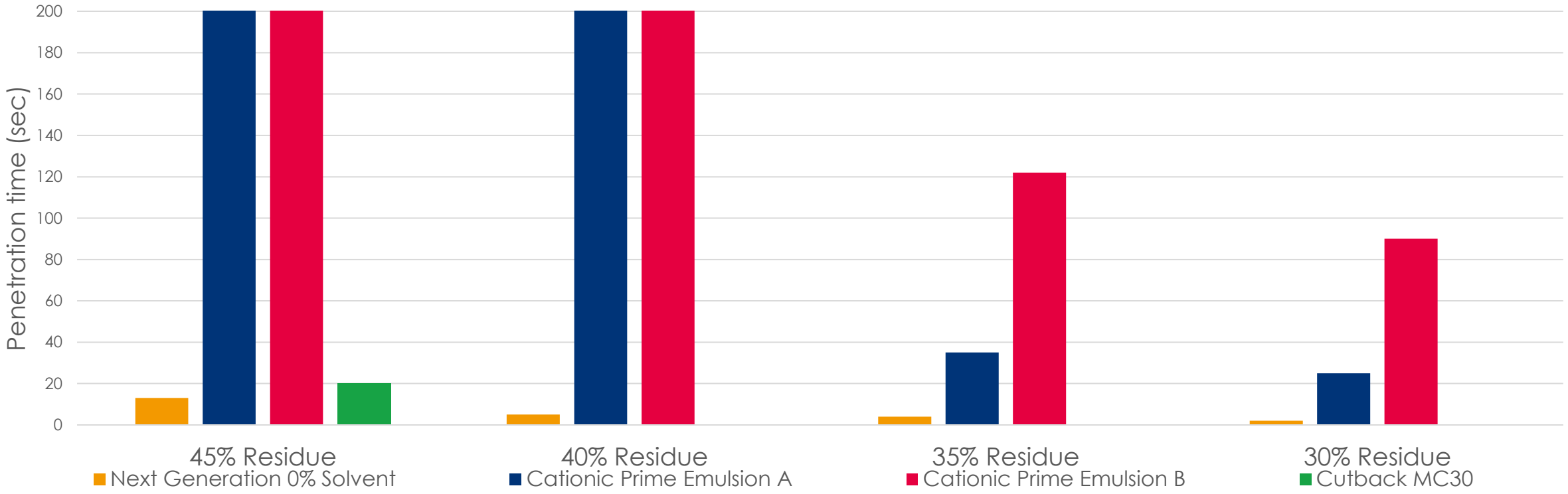
SURFACE IS TOUGHENED WITH NORMAL PAVING GRADE BINDERS

NEXT-GENERATION CATIONIC PRIME COAT EMULSION PERFORMANCE



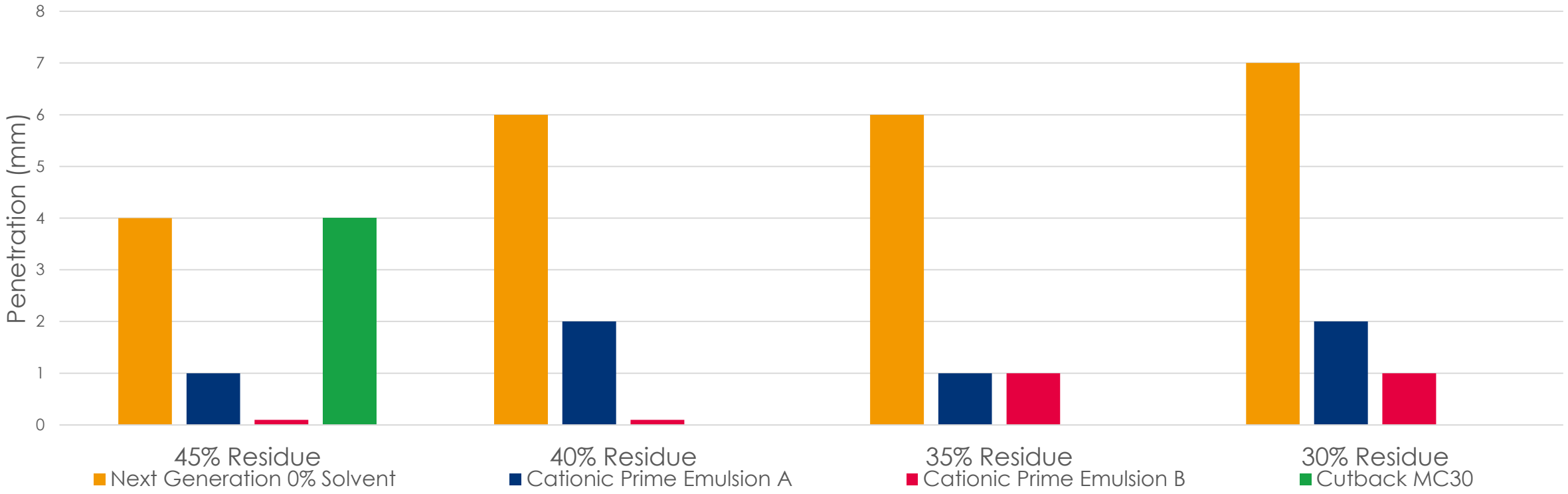
NEXT-GENERATION SOLVENTLESS FORMULA MEETS OR EXCEEDS 20% SOLVENT SYSTEMS

NEXT-GENERATION CATIONIC PRIME COAT EMULSION VS. STANDARD PRIME PENETRATION TIME



NEXT-GENERATION SOLVENTLESS FORMULA EXCEEDS TYPICAL SOLVENTLESS PRIME EMULSION

NEXT-GENERATION CATIONIC PRIME COAT EMULSION VS. STANDARD PRIME PENETRATION



NEXT-GENERATION SOLVENTLESS FORMULA EXCEEDS TYPICAL SOLVENTLESS PRIME EMULSION

SUMMARY

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WHAT WE KNOW

Average soil capillary radius is 6.8 µm

- Smaller asphalt emulsion particle size is better
- Deformable asphalt is helpful

Keep emulsion viscosity low

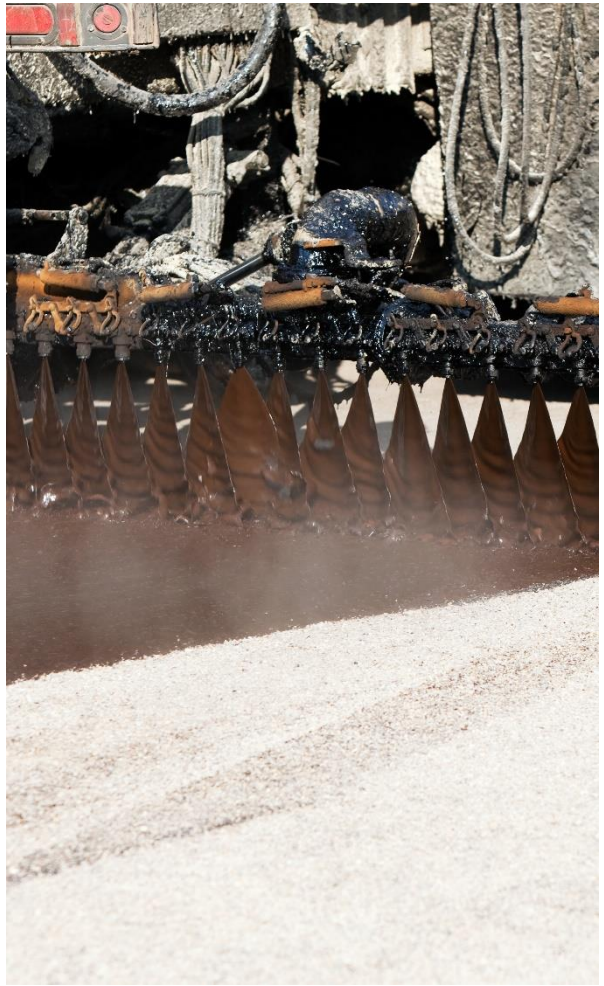
- Viscosity opposes capillary pressure

Maintain sufficient aqueous phase volume

- When the aqueous phase expends, asphalt particle penetration stops

Emulsifier is a critical component

- Provides sufficient chemical to afford wetting – aggregate dependent
- Low surface tension is preferable



THE FUTURE OF PRIME COATS – OUR NEXT-GENERATION SOLUTION

- **Potential to eliminate volatile organic compounds (VOCs)**
  - Environmentally friendly with improved worker safety and comfort
- **Fast-penetrating prime coat emulsion**
- **No need to apply sand**
- **Potential to pave the same day**
  - No waiting for days for a complete cure
- **Faster return to traffic**
  - A few minutes vs. a few days if choosing to pave later
- **Lower risk of vehicle damage**

ARKEMA-ROAD SCIENCE'S NEXT-GENERATION PRIME COAT EMULSIFIER

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UNCOVERING THE SCIENCE OF PENETRATING PRIME EMULSIONS

QUESTIONS?

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