Moisture damage of asphalt mixes: Causes and remedies

Centre for Transportation Engineering & Planning in collaboration with the Alberta Public Works Association presents
The Western Canada Pavement Workshop - 2010 Edition
Outline

- Definitions
- Mechanisms
- Remedies
- Evaluation tests
- Conclusions
Definitions

● **Stripping (Kiggundu and Roberts, 1987)**:
  ● The progressive functional deterioration of a pavement mixture by loss of the adhesive bond between the asphalt cement and the aggregate surface and/or loss of the cohesive resistance within the asphalt cement principally from the action of water.

● **Moisture damage (Caro et al, 2008)**:
  ● What Kiggundu and Roberts called stripping is Moisture damage.
  ● Stripping is a distress caused by moisture damage just as:
    ● Displacement (= stripping)
    ● Ravelling
    ● Hydraulic scour…

Moisture damage = Complex process:
- Chemical
- Physical
- Mechanical

Water exposure
- Liquid or vapor
- From top or bottom

Pavement deterioration
Moisture damage mechanisms
Moisture damage mechanisms

1. Moisture transport to binder/aggregate interface:
   - Infiltration of surface water
   - Capillary rise of subsurface water
   - Permeation or diffusion of water vapor

2. Response of the system:
   - Detachment/debonding
   - Displacement/stripping
   - Dispersion of the mastic
   - Film rupture/microcracks
   - Desorption of the mastic
   - Spontaneous emulsification

Aggravating factors

Hydraulic scouring

Pore pressure
Aggravating factors

Salting

Freeze-thaw cycle
Structure of asphalt mixture

Electron microscope pictures of a dense graded mix

Binder/mineral interface is present at all scales in the mix
Mechanisms at binder / aggregate interface

- Film rupture (mechanical, chemical reaction, dust)
- Displacement (thermodynamic, chemical)
- Detachment (thermodynamic, chemical)
- Surface free energy (thermodynamic)
Binder / silica aggregate interface

- Asphalt is mainly non polar
- Aggregate surface is polar
- Water is polar
Binder / silica aggregate interface

- Some chemicals in the asphalt have some affinity with silica surface
  - Acids and anhydrides
- Bond is too weak compared to water
  - Even weaker when deicing salt is present

Desorption/Displacement
Binder / limestone aggregate interface

- Same chemicals in the asphalt have some affinity with limestone surface
  - Acids and anhydrides

- Salt can be formed at interface

慎重: Calcium salts are poorly soluble in water → displacement is slowed down
Mechanical interlocking

- Asphalt binder is forced into the irregularities of the aggregate surface producing a mechanical interlock.

Moisture resistant interface  Moisture sensitive interface

 Aggregate with rough surface texture are more resistant to moisture damage
In most of the studies about moisture damage in asphalt mixes related to asphalt/binder interface properties, aggregate characteristics are considered the most critical parameter.

Asphalt is only playing a role when standard quality is not used: Bad quality asphalt (high paraffin content) or on the contrary high performance asphalt (polymer modified).
Remedies
Slowing down moisture transport

- **Good mix design**
  - Good drainage for open graded mix
  - Low permeability for dense graded mix
    - Control of air void distribution
    - Control of air void average size
    - Air void $< 8\%$ is not a guaranty

- **Good construction practices**
  - Avoid microcracks during compaction step
  - Achieve good density at joints
  - Drainage capability of untreated subbase and good moisture damage resistance of base course
Strengthening of binder and aggregate bonding

- Avoid use of highly moisture sensitive aggregates when possible

- Systematically add antistripping agent when moisture sensitive aggregates are used in a mix
  - Liquid antistrip
  - Hydrated lime / Hydraulic cement
Hydrated lime benefits

- Make silica looks like limestone
  - $2 \text{ Si-O-H} + \text{Ca(OH)}_2 \rightarrow (\text{Si-O})_2\text{Ca} + 2 \text{H}_2\text{O}$
  - Calcium hydroxide crystals deposit on silica surface

- Enhance moisture resistance properties of the binder
  - $2 \text{RCO-O-H} + \text{Ca(OH)}_2 \rightarrow (\text{RCO-O})_2\text{Ca} + 2 \text{H}_2\text{O}$
  - Calcium salt are not soluble in water

- Modify mastic rheology and resistance to aging
  - Better resistance to rutting and cracks
  - Better mechanical interlock

![SEM picture of lime crystals](image-url)
Liquid antistrip benefits

- **Make aggregate hydrophobic**
  - Wetting of aggregate by asphalt binder is enhanced in dry and wet conditions
  - Better coating and mechanical interlocking
  - Better resistance to displacement by water

- **Enhance moisture resistance of the binder**
  - Weak bonding acids are replaced by strong bonding amines at the interface

Better chemical compatibility and moisture resistant bonding
Test methods to evaluate moisture damage potential of a mix
Mainly used tests

- **Tests of the mix**
  - Lottman modified AASHTO T283
  - Root – Tunnicliff ASTM D4867
  - Hamburg wheel tracking test (Texas)

⚠️ Void content close to what is observed on the field

- **Test of the binder/aggregate interface**
  - Boiling test
  - Boiling test with salted water
AASHTO T283 and ASTM D4867

- Marshall or gyratory compacted Cores with 7% (1) air voids
- Specimen conditioning (2 separated sets):
  - Reference: ambient temperature
  - Conditioned: partial vacuum saturation in water (55-80%), 15 hours at –18 °C, 24 hours at 60 °C
  - All samples: 2 hours at 25 °C in water

- Mechanical test: Indirect Tensile Strength (50 mm/mn)

- Result: Tensile Strength Ratio (wet/dry)

- Limits: high dispersion of results, very sensitive to air voids even in the standard window, is the threshold really significant (70 to 85% depending on agencies)
Hamburg wheel-tracking test

- Repeated steel wheel passes on a compacted sample immersed in heated water (60 °C)

- Result: rut depth after thousands of cycles or number of cycles before failure (requirements depend on binder PG)

- Limits: very tough test that can eliminate some good mixes.
Boiling test (ASTM D3625)

- Add loose HMA to boiling water and measure the percentage of total visible area of aggregate surface that retains its asphalt binder coating.

  Good moisture resistance of binder / aggregate interface

  Low moisture resistance of binder / aggregate interface

Can be done also with salted water.

- Limits: Results are subjective, conditions are far from reality. It is only to check the strength of binder / aggregate interface and can be used in a comparative way.
Conclusions

- Moisture damage in hot mix asphalt is a complex process that costs a lot of money every year.

- Two main actions can be considered to prevent it:
  - Slowing moisture transport by proper mix design and good construction practices.
  - Strengthening of AC binder and aggregate interface bond by use of adhesion promoters like hydrated lime or liquid amines antistrip.

- Systematic use of adhesion promoter should be seen as an insurance:
  - You often need it more than you think and if you don’t have one when a problem occurs it costs you really more than what you would have paid for it.