QA/QC Pavement Consultancy Services Project

Workshop: Cold-Mix Recycled Asphalt

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Presentation outline

• Context

• Introduction
  o RAP complexity
  o Available technologies
  o Current goals

• Focus on cold-recycling of RAP
  o Compaction
  o Mechanical properties
  o Mix-design
  o Life Cycle Analysis

• Current studies
Pavement Section - Traffic Class T6 Subgrade Class S1 (QHDM 1997)

Context

Use of standard materials as per QCS 2014

Needs:

- Reduce construction costs
- Enhance Qatar self-sufficiency
- Reduce environmental impact
- Increase overall sustainability
- Encourage new business opportunities

→ RECYCLING
Context

Ashghal Circular for Use of Recycling Material

Qatar Strategy
Sustainability of Economic Prosperity
Development of Economic Infrastructure
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Context

Needs:

- Identification of recyclable materials in Qatar
- Selection of recycling technologies
- Verification of local technological feasibility - Field Trials
- Enforcement and definition of strategic goals
- Creation of Qatar-specific know-how (Fundamental Research and Pilot Projects)
- Development of design tools (specifications and procedures)
Official Circular, May 10th, 2018

Introduction

The complex nature of RAP: inert aggregate or reactive composite?

Concept of RAP as a “grey” aggregate
Available technologies:

- Hot-mix, Warm-mix, Cold-mix: is it only a matter of temperature?
- Rejuvenators, fluxing agents, (placebo?) …

Current goals:

- Increase quantity of recycled RAP
- Increase reliability of processing and production
- Simplify approach to design and quality control
- Reduce environmental impact and increase sustainability

Cold recycling of RAP
Research experience and full scale applications since 1998
RAP cold recycling

RAP
(load-bearing skeleton)

Emulsion
(new binder)

Added water
(wettability and workability)

Filler
(void filling and stiffening)

Virgin aggregates
(size distribution integration)

Cold-recycled bituminous mixtures are completely different from standard hot mixtures
RAP cold recycling

Aged bitumen films

Fluid phase (t)

Compaction
Mechanical properties

Need of specific:
• Characterization methods
• Constitutive models

Performance-based mix-design
RAP cold recycling - Compaction

Torino-Milano A4 Motorway 2001
RAP cold recycling - Compaction

Field trial 2002
RAP cold recycling - Compaction

Milano-Napoli A1 Motorway 2011
RAP cold recycling - Compaction
RAP cold recycling - Compaction

Equipment for static compaction (in the field)
RAP cold recycling - Compaction

Equipment for static compaction (in the field)
RAP cold recycling - Compaction

Equipment for static compaction (in the field)

Vertical pressure: 6050 kPa
Compaction time: 5 minutes
Mould diameter: 101.6 and 150 mm

N.B. controlled waiting time
RAP cold recycling - Compaction

Equipment for static compaction (in the field)

Oven drying (40°C)

Dry density (and voids content)

Paraffin-coated specimens
Equipment for gyratory compaction (in the laboratory)
RAP cold recycling - Compaction

Equipment for gyratory compaction
(in the laboratory)

Vertical pressure: 600 kPa
Rotation angle: 1.25°
Rotation speed: 30 rpm
Number of gyations: from 100 to 180
Mould diameter: 100 and 150 mm

N.B. controlled waiting time
RAP cold recycling - Compaction

Equipment for gyratory compaction (in the laboratory)

Dry density (and voids content)
Compaction curve (and parameters $C_{1g}$ and $K_g$)
RAP cold recycling - Mechanical properties

In the short term:
Possible phenomena of deformation accumulation and localized failure

In the long term:
Possible microcracks due to excessive stiffness and brittleness
**RAP cold recycling - Mechanical properties**

**Stiffness (Elastic modulus)**

*Effect of curing time*

- **Binder course mix 80/100**: 3500 MPa
- **Binder course mix 60/70**: 4160 MPa

Graph showing the effect of curing time on the elastic modulus. The diagram includes data points for standard preparation and 150 kN – 5 min.
Stiffness (Elastic modulus)
Effect of curing time

\[ E = E_1 + k_E \cdot \log_{10}(\text{days}) \]

Long term

Short term
Stiffness (Elastic modulus)
Effect of curing temperature

- Curing at 20°C
- Initial curing at 60°C
- After curing at 60°C

Maturazione a 20°C
Dopo la maturazione preliminare
Collegamento 80/100: 3500 MPa
Collegamento 60/70: 4160 MPa

Maturazione (giorni)
Modulo elastico [MPa]
Tensile strength (indirect)

Effect of curing time

\[ ITS = ITS_1 + k_{ITS} \cdot \log(t) \]

- For 101.6 mm specimens:
  \[ ITS = 0.467 + 0.281 \log t \]

- For 150 mm specimens:
  \[ ITS = 0.238 + 0.290 \log t \]
Fatigue resistance

Effect of curing temperature

![Graph showing the effect of curing temperature on fatigue resistance. The graph includes data points for curing at 20°C, initial curing at 60°C, initial curing at 40°C, standard wearing (%v=3), open wearing (%v=5.4), and standard binder (%v=7.4). The relationship is modeled by the equation $y = 1371.5x^{0.293}$ with a correlation coefficient $R^2 = 0.8857$.](image-url)
RAP cold recycling - Mechanical properties

Resistance to accumulation of permanent deformation

- Constant stress (creep)
- Repeated load axial (RLA)
RAP cold recycling - **Mix design procedure**

- Preliminary phase: selection of component materials
- Phase I: definition of optimal fluid phase dosage
- Phase II: definition of optimal emulsion and water dosages
Selection of the combination of RAP fractions:

- Reference size distributions of extracted aggregates
- Comparative evaluation (optional)
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- reference size distributions of extracted aggregates
- comparative evaluation (optional)
Selection of binder (emulsion)
- rheological testing of filler-emulsion systems + electronic microscopy
- comparative evaluation (optional)

Preliminary phase: selection of component materials

RAP cold recycling - Mix design procedure
Selection of binder (emulsion)

- rheological testing of filler-emulsion systems + electronic microscopy
- comparative evaluation (optional)
selection of binder (emulsion)

- rheological testing of filler-emulsion systems + electronic microscopy
- comparative evaluation (optional)
Preliminary phase: selection of component materials

Selection of filler:
- rheological testing of filler-emulsion systems + electronic microscopy
- comparative evaluation (optional)

Interconnected binding matrix
High modulus, high strength

Porous binding matrix
Low modulus, low strength
Preliminary phase: selection of component materials

Selection of filler:
- rheological testing of filler-emulsion systems + electronic microscopy
- comparative evaluation (optional)

\[ E_{\text{quicklime}} = 53,615 \times \text{(days)} + 530.51 \]
Phase I: definition of optimal fluid phase dosage

Tests on RAP-filler-water model systems:

- evaluation of dry density
- evaluation of workability
RAP cold recycling - Mix design procedure

Phase I: definition of optimal fluid phase dosage

Tests on RAP-filler-water model systems:

- evaluation of dry density
- evaluation of workability
Phase II: definition of optimal emulsion and water dosages

Partition of fluid phase between emulsion and added water
- Volumetric, mechanical and workability properties

\[ \%FF_{\text{optimum}} = \%w_{\text{added}} + (a_w + K \cdot b_b) \cdot \%E \]

\%FF_{\text{optimum}} (from Phase I): 4.5\% - 5.0\% (typical values)

\( a_w \): Water content of emulsion (e.g. 0.4 for a 60% bitumen emulsion)
\( b_b \): Bitumen content of emulsion (e.g. 0.6 for a 60% bitumen emulsion)

\( K \): Fluidity index of the bituminous residue of emulsion (0\% - 1\%) (e.g. 0.75)

Select the \%w_{\text{added}} and \%E combinations that satisfy design equation (for further testing)
Phase II: definition of optimal emulsion and water dosages

**Partition of fluid phase** between emulsion and added water

- volumetric, mechanical and workability properties
Phase II: definition of optimal emulsion and water dosages

**Partition of fluid phase** between emulsion and added water

- **volumetric, mechanical** and workability properties

![](chart.png)

**Optimal emulsion content, **\( \%E_{opt} (\%) \) vs Fluidity index, **\( K \)**

- **G\_dry**
- **ITS**

**RAP cold recycling - Mix design procedure**
Phase II: definition of optimal emulsion and water dosages

Partition of fluid phase between emulsion and added water

- volumetric, mechanical and workability properties

RAP cold recycling - Mix design procedure

Indirect tensile strength ITS [N/mm²]

% Emulsion

20°C k=0.75  20°C k=0.50
Extra focus on **short term behavior** - Experimental

Characterization as unbound granular material
• triaxial cell tests (resilient modulus and p-q failure limits)
Extra focus on **short term behavior** - Experimental

Characterization as unbound granular material

- triaxial cell tests (resilient modulus and p-q failure limits)
RAP cold recycling - Mix design procedure +

Extra focus on **short term behavior** - Modelling

Numerical analysis with non linearity of cold-recycled layer
RAP cold recycling - Mix design procedure +

Extra focus on **short term behavior** - Modelling

Numerical analysis with non linearity of cold-recycled layer
Extra focus on **short term behavior** - Modelling

Numerical analysis with non linearity of cold-recycled layer
LCA as part of pavement design, mix design and quality assurance

LCA “transparent” procedure:
- SimaPro 7.3 software
- Purpose-built Life Cycle Inventory (LCI) database

SCENARIO 1 (with RAP) in Milano-Napoli A1 Motorway 2011

SCENARIO 2 (design reference)
LCA as part of pavement design, mix design and quality assurance

“Transparent” procedure:
- SimaPro 7.3 software
- Purpose-built Life Cycle Inventory (LCI) database

Gross Energy Requirement (GER) (i.e. overall energy spent):
Scenario 2 >> Scenario 1
42% reduction
LCA as part of pavement design, mix design and quality assurance

“Transparent” procedure:
- SimaPro 7.3 software
- Purpose-built Life Cycle Inventory (LCI) database

Global Warming Potential (GWP) (i.e. greengas emission):
Scenario 2 >> Scenario 1
37% reduction
Further investigations are being carried out in:

QSD Ashghal, Doha, Qatar
“Ashghal Center for Research & Development” (ACRD)

Politecnico di Torino, Turin, Italy
“Experimental Laboratory of Innovative and Recycled Materials for Civil Engineering Infrastructures” (MIR)
Thank you
For further information please visit the “Qatar Future Roads” website http://www.q-roads.com.qa/