International Workshop
Asphalt Recycling and Materials Re-Use
in Asphalt Pavements

Cold recycling of bituminous mixtures

prof. Ezio Santagata
Politecnico di Torino

Università di L'Aquila - Facoltà di Ingegneria - 28th June 2007

Cold recycling of bituminous mixtures
Self introduction

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Guidelines for presentation

1. Give general overview of the topic
2. Highlight interest/problems of society, users, road owners, designers and contractors
3. Give some examples about specific solutions or problems
4. Point out main key players in research

SPECIFIC AND OPEN QUESTIONS
RESEARCH NEEDS

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Cold recycling of bituminous mixtures

General description

- RAP (reclaimed asphalt pavement)
  - bulk structure
- Bituminous emulsion
  - binder
- Filler (usually Portland cement)
  - filler and stiffening enhancement
- Added water
  - Workability and emulsion dispersion
- Virgin aggregates
  - integration to bulk structure

In-field recycling (single or multiple unit)

In-plant recycling

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General description

• Advantages:
  – Reduced use of raw materials
  – Reduction of disposal volumes
  – Lower environmental impact
  – Lower energy consumption
  – Reduced impact on labour health and safety
  – Cost reduction

• Disadvantages:
  – Reduced structural performance
  – Problems in mix design, testing and modelling

However, based on engineering experience, there are guidelines and specifications!

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Critical issues derived from research experience

• Rehabilitation of motorway A4 Torino-Milano (1999-2001)
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Critical issues derived from research experience

- Rehabilitation of motorway A4 Torino-Milano (1999-2001)
  - Production homogeneity

<table>
<thead>
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<th>Day of monitoring</th>
<th>Measured</th>
<th>Expected</th>
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Cold recycling of bituminous mixtures
Critical issues derived from research experience

• Rehabilitation of motorway A4 Torino-Milano (1999-2001)
  – Compaction

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Critical issues derived from research experience

• Load spreading function

EVALUATION OF STIFFNESS AND STRENGTH
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Critical issues derived from research experience

• Problems to solve:
  – Testing technique
  – Sample preparation / coring

Selection of practical characterization techniques
Development of equipment and procedures

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Critical issues derived from research experience

• Field compaction (static)

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Critical issues derived from research experience

• Field compaction (static)

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• Laboratory compaction (gyratory)

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• Elastic stiffness testing (RLIT)

![Graph showing elastic stiffness testing](image)

- Elastic stiffness testing (RLIT)
  - Binder course mix 80/100: 3500 MPa
  - Binder course mix 60/70: 4160 MPa

• Indirect tensile strength (ITS) testing (static)

![Graph showing indirect tensile strength testing](image)
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- Fatigue testing

\[ y = 1371.5x - 0.2153 \]
\[ R^2 = 0.8657 \]

Initial strain (in microstrains)

Preconditioning standard
Preconditioning at 60°C
Preconditioning at 40°C
Usura ANAS (\( v = 3.2\% \))
Usura aperta (\( v = 5.4\% \))
Usura Collegamento ANAS (\( v = 7.8\% \))

Long term

\[ E = E_0 + k \cdot \log_{10}(\text{days}) \]

Short term

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Critical issues derived from research experience

- Elastic stiffness parameters ($E_1$ and $k$) extremely sensitive to variations of:
  - Size distribution
  - Emulsion type
  - Compaction

<table>
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<tbody>
<tr>
<td>$E_1$</td>
<td>1429</td>
<td>569</td>
<td>1256</td>
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<tr>
<td>$k_E$</td>
<td>1388</td>
<td>921</td>
<td>1591</td>
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<tr>
<td>$E_{60}$</td>
<td>3897</td>
<td>2206</td>
<td>4084</td>
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Lower binder content, coarser RAP, higher air voids

\[
\text{ITS} = 0.467 + 0.281 \log t
\]

\[
\text{ITS} = 0.238 + 0.290 \log t
\]

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Cold recycling of bituminous mixtures
Critical issues derived from research experience

- ITS parameters ($RTI_1$ and $k_{RTI}$) extremely sensitive to variations of:
  - Size distribution
  - Emulsion type
  - Compaction

\[
\begin{array}{c|c|c}
\text{Day of monitoring} & \text{Upper binder content} & \text{Lower binder content} \\
0 & 1 & 2 \\
1 & 2 & 3 \\
2 & 3 & 4 \\
3 & 4 & 5 \\
4 & 5 & 6 \\
5 & 6 & 7 \\
6 & 7 & 8 \\
7 & 8 & 9 \\
8 & 9 & 10 \\
9 & 10 & 11 \\
10 & 11 & 12 \\
11 & 12 & 13 \\
12 & 13 & 14 \\
\end{array}
\]

Lower binder content, coarser RAP, higher air voids

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- Evolution of water content

\[
\begin{array}{c|c|c}
\text{Curing time, } t \text{ (days)} & \text{Water content (%)} & \text{Elastic stiffness, } E \text{ [MPa]} \\
0 & -0.8 & 4400 \\
10 & -0.7 & 3400 \\
20 & -0.6 & 2400 \\
30 & -0.5 & 1400 \\
40 & -0.4 & 400 \\
50 & -0.3 & 200 \\
60 & -0.2 & 100 \\
70 & -0.1 & 10 \\
\end{array}
\]

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• Evolution of water content

\[ I/T/S \text{ [N/mm}^2] \]

\[ \text{Water loss (\%)} \]

\[ 0,4 \quad 0,5 \quad 0 \quad 1 \quad 02 \quad 03 \quad 04 \quad 05 \quad 06 \quad 07 \quad 0 \]

Curing time, \( t \) (days)

\[ \begin{align*}
0,6 & \quad 0,7 & \quad 0,8 & \quad 0,9 & \quad 1,0 \\
5,5 & \quad 6,0 & \quad 6,5 & \quad 7,0 & \quad 7,5 & \quad 8,0 \\
\end{align*} \]

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• Effect of curing temperature

\[ \text{Modulazione a } 20^\circ\text{C} \]

\[ \text{Modulazione preliminare a } 60^\circ\text{C} \]

\[ \text{Dopo la modulazione preliminare} \]

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• Effect of emulsion type and quantity

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• Effect of filler type (cement vs quicklime)
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- Compaction properties (from gyratory equipment)

![Graph 1](image1)

![Graph 2](image2)
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Critical issues derived from research experience

- Mix design

![Graph showing dry density vs. water content]

- Mix design

![Graph showing workability vs. water content]
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Critical issues derived from research experience

• Mix design

\[ \%\text{FF}_{\text{optimum}} = \%\text{w}_{\text{added}} + (a + Kb) \cdot \%E \]

- Short term characterization
  - UNBOUND?

• Resilient modulus \( M_R \)
• Failure (p-q) criteria
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Critical issues derived from research experience

• Short term characterization
  – UNBOUND?

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• Characterization of the emulsion-filler system

Interconnected binding matrix
High modulus, high strength

Porous binding matrix
Low modulus, low strength

Can production plants be improved?
Can compaction techniques be improved?
Should RAP be separated in fractions to control gradation?
Are rejuvenators needed?
Are modified emulsions needed?
What can of filler should be used?
How much stiffness is needed?
Options to mix design?
Options to performance testing?
Coring?
Field testing?
Thanks for your attention

ezio.santagata@polito.it