Experimental research

Thermal evaluation of sustainable asphalt pavements with energy harvesting purposes

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1. Motivation
2. Introduction
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The problem...

Chile has one of the highest solar radiation levels around the world. Urban-heat island effect...increment of temperature in urban zones.

How to solve this problem?...

Development of new construction materials...
The solution...

☑ Development of asphalt mixtures reinforced with metallic waste.

1) Improvement in mechanical properties...extend the service life of asphalt pavements.

2) Improvement in thermal properties...increase of the thermal comfort in urban zones.

Main goal:

To evaluate the influence of the type and content of metallic waste on the thermal behaviour of asphalt mixtures and their use as solar radiation absorbent material.
Materials and Methods

5 different asphalt mixtures: 1 asphalt mixture without metallic waste and 4 asphalt mixtures reinforced with 2%, 4%, 6% and 8% of metallic waste. 36 Marshall samples were fabricated.
Thermophysical properties of asphalt mixtures

1. Bulk density ($\rho_a$) and air void content (AVC)
2. Thermal conductivity ($\lambda$)
3. Specific heat ($C_p$)
4. Thermal diffusivity ($\beta$)
5. Solar irradiance simulation
6. Thermal behaviour of asphalt mixtures and solar collector under infrared radiation

Solar irradiance conditions in Concepción City:
- Summer season: 898.57 W/m²
- Winter season: 289.38 W/m²

Materials and Methods:
- Asphalt mixture
- 3 Marshall samples
- Thermal sensor
- Thermal analyser properties
- Infrared lamp
- Asphalt solar collector prototype
- Datalogger
- Thermocouples
- Insulating material
- Test chamber
- Height of simulation “h”:
  - 40 cm (Summer season)
  - 90 cm (Winter season)

Results and Discussion
- 1. Bulk density ($\rho_a$) and air void content (AVC)
- 2. Thermal conductivity ($\lambda$)
- 3. Specific heat ($C_p$)
- 4. Thermal diffusivity ($\beta$)
- 5. Solar irradiance simulation
- 6. Thermal behaviour of asphalt mixtures and solar collector under infrared radiation
### Results and Discussion

#### Average results of thermophysical properties in asphalt mixtures reinforced with steel wool fibres

<table>
<thead>
<tr>
<th>Fibre cont. (%)</th>
<th>$\rho_a$ (g/cm³)</th>
<th>AVC (%)</th>
<th>$\lambda$ (W/mK)</th>
<th>$C_p$ (J/kgK)</th>
<th>$\beta$ (x10⁻⁷) (m²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.347</td>
<td>6.86</td>
<td>1.343</td>
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<tr>
<td>Ref. 0%</td>
<td>2.356</td>
<td>5.83</td>
<td>1.406</td>
<td>957.93</td>
<td>6.230</td>
</tr>
</tbody>
</table>

#### Average results of thermophysical properties in asphalt mixtures reinforced with steel shavings

<table>
<thead>
<tr>
<th>Shavings cont. (%)</th>
<th>$\rho_a$ (g/cm³)</th>
<th>AVC (%)</th>
<th>$\lambda$ (W/mK)</th>
<th>$C_p$ (J/kgK)</th>
<th>$\beta$ (x10⁻⁷) (m²/s)</th>
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</thead>
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<td>5.813</td>
</tr>
<tr>
<td>Ref. 0%</td>
<td>2.356</td>
<td>5.83</td>
<td>1.406</td>
<td>957.93</td>
<td>6.230</td>
</tr>
</tbody>
</table>
Results and Discussion

Temperature evolution under steady-state condition in asphalt mixtures with steel fibres

Temperature evolution under steady-state condition in asphalt mixtures with steel shavings

Percentage of reduction in the heating rate in asphalt mixtures reinforced with 2%, 4%, 6% and 8% of metallic waste

<table>
<thead>
<tr>
<th>Fibres</th>
<th>0% fibres</th>
<th>2% fibres</th>
<th>4% fibres</th>
<th>6% fibres</th>
<th>8% fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td>94%</td>
<td>92%</td>
<td>85%</td>
<td>106%</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shavings</th>
<th>0% shavings</th>
<th>2% shavings</th>
<th>4% shavings</th>
<th>6% shavings</th>
<th>8% shavings</th>
</tr>
</thead>
<tbody>
<tr>
<td>89%</td>
<td>83%</td>
<td>76%</td>
<td>69%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

✅ Morphology and distribution of steel fibres together with the improvement on the thermal properties in mixtures with fibres were the most influential variables during the first hours of heating.

Steel fibres v/s Steel shavings
Main results...

- Asphalt mixtures with 4% of fibres increased their heating rates and decreased their cooling rates, being appropriate to develop an asphalt solar collector prototype.

- Under the minimum and maximum solar irradiance values simulated, the water inside the asphalt solar collector prototype reached a temperature of 33°C and 53°C, respectively.
1. Density of asphalt mixtures with metallic waste was reduced with the air void content increase, that was mainly attributed to the total volume variation of each specimen, rather than the variation of the mass.

2. Thermal conductivity and specific heat of asphalt mixtures were reduced with the addition of metallic waste. However, the incorporation of steel wool fibres in asphalt mixtures caused an increase on their thermal diffusivity, decreasing the influence of air void on the heat transfer through the mixtures.

3. Under steady-state heating, asphalt mixtures with fibres increased their heating rate during the first hours under infrared radiation. In contrast, under transient-state heating, just in the case of asphalt mixtures with 4% of fibres an increase on the heating rate and a decrease on the cooling rate was registered.

4. It was proven that the asphalt solar collector with 4% fibres was able to transfer heat from the pavement surface to the water flowing inside it, and that the water reached a temperature of 53°C under the maximum irradiance conditions.