Performance of Artificial Aggregates used in Chipseal Surfaces in New Zealand

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Overview

- **Introduction**
- **The Laboratory Experiment**
  - Preparing Samples
  - Accelerated Polishing
- **Experimental Results**
  - Greywacke Aggregate
  - Melter Slag
  - Electric Arc Furnace Aggregate
  - Calcined Bauxite
  - Combined Results
- **SEM Photographs**
- **Conclusions**
Many things are the same… BUT there are also some significant differences
The NZ Roading context
New Zealand is...

- Geologically VERY young
  - Many difficult soils
- Geologically VERY variable
  - Many different subgrade conditions
  - Many different construction materials
- Environmentally variable
  - Many different climatic zones
Typical NZ State Highway
Engineering Qualities needed in Surface Aggregate

- **Toughness** - resistance to slow crushing and resistance to rapid loading;
- **Hardness** - resistance to abrasion / attrition;
- **Resistance to polishing** (for wearing course materials and chip sealed surfaces);
- **Resistance to stripping** - ability to maintain adhesion to any bituminous binder with which the aggregate is used;
- **Resistance to weathering effects** in the pavement (e.g. resistance to frost action, swelling and softening by water); and
- **Ability to contribute to strength and stiffness** of total mix by intrinsic aggregate strength and shape properties.

Rubber sliding on pavement aggregate

Deformation leading to hysteresis

Rubber-stone adhesion

Source: John Oliver ARRB Transport Research
Generalised Pavement Surfacing Polishing Model

- Initial Roughening
- Polishing Phase
- Equilibrium Phase
- Seasonal Variations

>6 Million Equivalent single axle loads

After 1M standard Axles: approximately 2 years

Source, Prowell et al., 2003

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The PSV Test – Stage 1

BS 812 – Pt 114, 1989;
EN 1097/8; ASTM E303

Stage 1:

- Prepare slightly curved test samples of cubic shaped 10mm sized aggregate chippings
- Accelerated polishing for 6 hours with added polishing agents (corn emery and emery flour) in the accelerated polishing machine
The PSV Test – Stage 2

BS 812 – Pt 114, 1989;
EN 1097/8; ASTM E303

Stage 2:

- Measure wet skid resistance with BPFT
- Result of PSV test is a laboratory determined polished stone value PSV or SRV (30-80)
- PSV is an ‘end of test’ result.
<table>
<thead>
<tr>
<th>Pavement Surf Agreg factors</th>
<th>Load factors</th>
<th>Environmental factors</th>
<th>Vehicle Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological properties of aggregate</td>
<td>Age of the surface</td>
<td>Water film thickness / drainage</td>
<td>Vehicle speed</td>
</tr>
<tr>
<td>Surface texture (microtexture and macrotexture)</td>
<td>Traffic intensity and composition</td>
<td>Surface contamination</td>
<td>Angle of the tyre to the direction of the vehicle</td>
</tr>
<tr>
<td>Chip size and shape</td>
<td>Road geometry</td>
<td>Temperature</td>
<td>The wheel slip ratio</td>
</tr>
<tr>
<td>Type of surfacing (concrete, asphalt mix and mix design, chip seal)</td>
<td>Traffic flow conditions</td>
<td>The combined ‘seasonal effects’ and short-term variations</td>
<td>Tyre materials (structural type, hardness and wear)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rainfall</td>
<td>Tyre tread depth and pattern</td>
</tr>
</tbody>
</table>
Greywacke – High PSV (63-65)

- **Coarse grained greywacke** - Cretaceous age
  - Having experienced only diagenetic zone metamorphism
  - Typically weakly lithified sandstone as individual minerals and lithic grains are coated with clay minerals
  - Clay often swells and thus the grains are easily dislodged
  - Quite different to other greywackes in NZ
NZ Melter Slag Artificial Aggregate

New Zealand Steel (Glenbrook)
- Irons and/Coal/Limestone

Pacific Steel (Otahuhu)
- Steel Scrap

Iron making or “Melter” Aggregate
- Steel making or “KOBM” aggregate
- “Blend”

Sub-base/Base course Drainage/surfacings
Road stabilisation
Farm tracks Temporary Roads
Surfacing Aggregates

Source: SteelServe Ltd (2005)
Melter Slag Aggregate - Medium PSV (55-58)

- From titanomagnetite sands enriched in titanium
- Appear metallic and contain many gas vesicles
- Contains large cubic crystals of blue-green magnesium (Mg) rich spinel mantel with red-brown pseudobrookite (Ti-rich oxide)
- Matrix shows typical quench texture

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NZ Electric Arc Furnace Artificial Aggregate

New Zealand Steel (Glenbrook)
- Irons and/Coal/Limestone
  - Iron Making or “Melter” Aggregate
  - Steel making or “KOBM” aggregate
- “Blend”
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  - Road stabilisation
  - Farm tracks
  - Temporary Roads
  - Surfacing Aggregates

Pacific Steel (Otahuhu)
- Steel Scrap

Source: SteelServe Ltd (2005)
Electric Arc Furnace Aggregate - Medium PSV

- By product of steel from charge of iron and steel scrap and a lime flux
- The EAF is finer grained than MS with more even grain size
- Consists dominantly of calcium rich compounds (e.g. larnite, ranknite, calcic pyroxenes and wustite)
- It lacks the titanium oxides (needle like form) that typify the MS

EAF Thinsection

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Calcined Bauxite – High PSV (70+)

- Imported from China
- Good SR performance experience in NZ and internationally on sites with high risk of braking (e.g. approaches to pedestrian Xings)
- CB consists dominantly of fine grained brownish corundum crystals inter dispersed with areas of colourless columnar mullite crystals
- X-ray diffraction also indicates presence of iron oxide

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UoA Lab Testing Methodology Process

A prepared Lab Sample

The Accelerated Polishing Machine

The Dynamic Friction Tester

Greywacke Aggregate DFT(μ) Stage 1 and 2 Polishing

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Greywacke - Stage 1 Polishing

Initial Unpolished Skid Resistance ($\mu$)

Un-polished Sample (Control)

Polished Sample

$y = 0.8828e^{-0.0319x}$
$R^2 = 0.8894$

$y = 0.0078x^2 - 0.1099x + 0.8695$
$R^2 = 0.9861$

'Steady State' Equilibrium Skid Resistance (ESR)

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Combined Results – Stage 1 - Wet polishing

Accelerated Polishing Duration - Time (hours)

DFF Tester CoF (μ)

- GR Pol
- GR Unpol
- MS Pol
- MS UnPol
- EAF Pol
- EAF Unpol
- CB Pol
- CB Unpol

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Combined Results – Stage 1 - Wet polishing

\[ y = 0.007x^2 - 0.055x + 0.904 \]
\[ R^2 = 0.989 \]

\[ y = 0.006x^2 - 0.065x + 0.887 \]
\[ R^2 = 0.982 \]

\[ y = 0.010x^2 - 0.118x + 0.875 \]
\[ R^2 = 0.995 \]

\[ y = 0.004x^2 - 0.016x + 0.647 \]
\[ R^2 = 0.098 \]

<table>
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<tr>
<th>DFT Tester CoF (μ)</th>
<th>Accelerated Polishing Duration - Time (hours)</th>
</tr>
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<tr>
<td>CB Pol</td>
<td>Poly. (CB Pol)</td>
</tr>
<tr>
<td>MS Pol</td>
<td>Poly. (MS Pol)</td>
</tr>
<tr>
<td>GR Pol</td>
<td>Poly. (GR Pol)</td>
</tr>
<tr>
<td>EAF Pol</td>
<td>Poly. (EAF Pol)</td>
</tr>
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</table>

CB PSV = 70+
MS PSV = 55
EAF PSV = ?
GR PSV = 63

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Stage 2 – Accelerated ‘Polishing’ with Additives

- **Oedometer clay** – a soft but well graded material predominantly (kaolinite) and is strongly anisotropic in terms of its properties, with a Moh’s hardness of 2-2.5;

- **Emery powder** - a fine but very hard material derived predominantly from corundum minerals (Al2O3) with a Moh’s hardness of 9. Emery powder is used in the PSV test machine as a polishing medium;

- **Leighton Buzzard sand** - a coarse and hard material is predominantly from quartz minerals with a Moh’s hardness of 7.
Greywacke - Stage 2 Polishing

‘Steady State’
Equilibrium Skid Resistance (ESR)

Effect of polishing with Leighton Buzzard Sand

Effect of polishing with Emery Powder
‘Before’ and ‘After’ SEM Photos - Greywacke

Unpolished Sample

Polished Sample

DF Tester (μ)

Time (mins)

Stage 1: Polishing to ESR

Stage 2: Polishing with Additives

‘Steady State’ Equilibrium Skid Resistance (ESR)

‘Steady State’ Equilibrium Skid Resistance (ESR)

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Figure 8(a) Coarse grained greywacke sandstone GR: unpolished surface x 200mag

Figure 8(b) Coarse grained greywacke sandstone GR: polished surface x 200mag

‘Before’ DFT ($\mu = 0.87$)  
‘After’ DFT ($\mu = 0.41$)
Figure 9(a) Melter Slag: unpolished surface x 200mag

‘Before’ DFT (µ = 0.90)

Figure 9(b) Melter Slag: polished surface x 200mag

‘After’ DFT (µ = 0.40)
Figure 10(a) Electric Arc Furnace EAF: unpolished surface x 200mag

‘Before’ DFT ($\mu = 0.69$)

Figure 10(b) Electric Arc Furnace EAF: polished surface x 200mag

‘After’ DFT ($\mu = 0.35$)
Figure 11(a) Calcined Bauxite (CB): unpolished surface x 200mag

‘Before’ DFT ($\mu = 0.90$)

Figure 11(b) Calcined Bauxite (CB): polished surface x 200mag

‘After’ DFT ($\mu = 0.79$)
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SEM Photographs of Aggregate Surface Textures

Unpolished Coarse Grained GR x 12,000 mag

Unpolished Melter Slag x 800 mag

Unpolished Calcined Bauxite x 1,000 mag

Polished GR x 200 mag DFT (µ=0.41)

Polished MS x 200 mag DFT (µ=0.40)

Polished CB x 200 mag DFT (µ=0.79)
Conclusions ...1

- **Greywacke sandstone SR performance**, 
  - Varies considerably and depends upon geological makeup, grain sizes and degree of lithification
  - Best known greywacke in NZ has a $-(dy/dx)$ slope that is much greater than artificial aggregates
  - As matrix is weakly cemented – abrasion is high

- **All artificial aggregates tested (MS, EAF and CB) performed much better than NZ’s best known natural aggregate** 
  - Calcined Bauxite (CB) with max 9.5mm sized aggregate chips performed the best – lost only 15% of initial SR
  - Melter Slag (MS) under wet polishing also performed almost as good as the CB during wet polishing
  - Electric Arc Furnace (EAF) because of its finer grain size matrix began with lower SR, but $-\Delta(\mu)$ during polishing was small during wet polishing (<10%)
Conclusions ...2

- The greywacke and the artificial aggregates ‘polish’ by different mechanisms....therefore deterioration rates $-\Delta(\mu)$ vary under the same accelerated polishing loads.

- SEM photographs and thin-sections of the aggregates that show grain size, microtexture, mineral makeup and hardness and type of bonding of the grain matrix of the rock can help explain the polishing behaviour.

- Stage 2 polishing with contaminants has shown that the MS and the EAF can ‘polish’ under extreme polishing conditions – however this does not seem to be reflected in field results.
Final Summary Findings

- PSV is a poor indicator of aggregates resistance to polishing – as it does not reflect the ‘steady state’ level of SR nor the ranking order of initial SR level
- Must consider abrasion / weathering as well as polishing abilities – the harder artificial aggregates weather well
- We must consider/develop other methods of predicting the performance of ‘steady state’ SR
- UoA laboratory test method shows promise – as does the Wehner Schulze (German device)
- Transport costs (distance travelled in cartage) is a significant factor in the economics of the surfacing

- Research is continuing....
Some Road Safety thoughts…

We must look at all possibilities to reduce the human toll (death and injury) on our Transport Systems – current rates (any rates?) are unacceptably high.

We need to do much better…. improvements that we seek will not occur without tackling the total system – including changing human behaviour and / or taking some control / freedoms away from the human / driver (eg ISA, Inhibitors)