Abstract
The surface friction characteristics of pavements are one of the key safety considerations for road authorities. One of the traditional repair methods to correct for low surface friction and/or texture loss is the application of a new surfacing layer.

There are several alternate techniques for correcting these deficient sites by rehabilitating the existing surface. These techniques include mechanical retexturing, water blasting and ultra high pressure (UHP) water cutting.

This paper describes the evolution of the UHP water cutter from its use solely for repairs prior to sealing to its success as a recognised resurfacing technique for micro-texture and macro-texture deficient surfaces.

Included in the paper are descriptions of laboratory experiments and case studies describing the performance of resurfaced sites after treatment.

Introduction
Ultra high pressure (UHP) water cutting was developed by Fulton Hogan as a response to the growing problem of excess bitumen on the surface of New Zealand roads and identification of friction and texture deficient sections of the network. These sites were identified by Transit New Zealand’s annual SCRM (Sideways Force Coefficient Routine Investigation Machine) survey. Low friction sites with excess bitumen binder were traditionally treated by burning (Figure 1). In 2000 the burning process was banned for both environmental reasons and the destructive effect it had on the surfacing structure.
Figure 1. Burning excess bitumen from a flushed chipseal (1999)

Figure 2. Micro and macro texture
Figure 3. First friction and texture monitoring trial

Figure 4. Water cutting a bitumen flushed chip seal surface
In June 2000 the first trial of an ultra high pressure pump with a small cutting head was carried out to remove excess bitumen from a flushed asphalt surface. Further texture and friction testing was carried out on treated surfaces during the development of the water cutting process. It was observed that the water cutting action not only removed the excess binder and detritus from the surface but was also cutting the surface of the stone, thereby refreshing the micro-texture (Figure 2). Early test results showed significant improvement to both the macro-texture and the micro-texture with significant improvements to skid resistance (Figure 3).

The positive results of these early trials lead to the development of a commercial UHP water cutter machine that has been used to restore the macro-texture on flushed sites throughout New Zealand and Australia (Figure 4). The UHP machine uses an umbilical cutting head attached to the ultra high pressure water source and the vacuum recovery system to remove eroded material. This technique allows the rehabilitation of bitumen rich areas.

The UHP water cutting process was developed to cut the uppermost pavement surface using high pressure water (2500 bar) producing a number of fine jets of water travelling at high velocity (1800 km/h). The fineness of the water jets means that the impact energy is dissipated at the surface layer allowing bitumen to be removed with minimal effect on the water proofing qualities of the pavement and with negligible chip loss. The UHP water cutter uses 85% less water than other lower pressure water blasting technologies. The frugal use of water enables the UHP water cutter to work continuously for up to six hours before needing to refill. The width of treatment can be varied from 200mm to 520mm per pass.

**Research Projects**

Laboratory testing was undertaken to scientifically confirm field observations that the UHP water cutting process was restoring the micro-texture of the stone surface. Normal polished stone value (PSV) specimens were created in accordance with BS812 (1989) Part 114. Initially the surface friction of these unpolished specimens was measured in the laboratory using a British Pendulum Tester. The samples then underwent accelerated laboratory polishing and the PSVs were again measured. The polished specimens were then clamped in a holding frame and treated with the UHP water cutter. Finally, the surface friction of the specimens was measured.

Figure 5 shows that the surface friction of polished specimens could be restored using a water cutting process.

<table>
<thead>
<tr>
<th>Type of stone [and source]</th>
<th>Skid resistance Laboratory PSV units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prior to polishing</td>
</tr>
<tr>
<td>Control</td>
<td>61</td>
</tr>
<tr>
<td>Greywacke [Uriti]</td>
<td></td>
</tr>
<tr>
<td>Blue Rock (Hard Rock) [Plimmerton]</td>
<td></td>
</tr>
<tr>
<td>Brown Rock (Overburden) [Plimmerton]</td>
<td></td>
</tr>
<tr>
<td>Greywacke [Pound Road] 20% rounded faces</td>
<td>72</td>
</tr>
<tr>
<td>Control</td>
<td>62</td>
</tr>
</tbody>
</table>

Figure 5. Micro-texture refreshment experiment data

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2 By comparison the speed of sound in dry air at 20°C is 1235 km/h
3 NZ patent application 517062
On the Northern Motorway in Christchurch a two coat seal was constructed in 1996. The seal had an expected life of ten years, however after six years parts of the seal were deemed to have failed due to low skid resistance. The low friction values were caused by a combination of polishing and bleeding. A continuous 300m length of the failed seal became a test site to trial the UHP water cutter. The site was divided into three sections:

- section 1 was water cut in January 2002
- section 2 was left untreated as a control
- section 3 was water cut in August 2002.

Figure 6 shows the texture and surface friction data for this site before and after water cutting. The results show that both texture and friction had slowly declined from 1998 to 2001. Following water cutting of section 1 in January 2002 and section 3 in August 2002, both the texture and friction values at both sites improved markedly. So far the water cutting has extended the life of both treated sections by four years, or 65% of the life of the previous surfacing and their performance suggests that these sections of the seal will last to their planned life of ten years without the addition of extra binder and chip sealing. The control section 2 has continued to deteriorate and will undergo water cutting to extend its life.

In 2003 Land Transport New Zealand funded a three-year research project entitled “Watercutting — investigating the lifecycle of water cutter rejuvenation of aggregates” (3). The aim of the research was to water cut polished surfaces on high stress high-risk sites on the state highway network and to monitor their surface texture and friction for three years.

Ten trial sites were chosen which had previously been identified as having low skid resistance but good macro-texture. These sites covered a range of surfacing types, aggregate types, traffic volumes, climate and varying road geometry. The surface types that were resurfaced included: chip seal (single and two coat), porous asphalt and a 10mm asphalt. Sites chosen for rehabilitation were sectioned with the majority of each site resurfaced with a traditional treatment and one section ranging from 130m to 200m long was water cut. The sites were monitored for skid resistance, texture, accidents, traffic, climate and a visual assessment of their performance.

Micro-texture data collected immediately before and after the UHP re-texturing process showed significant improvements on all sites and a measurable increase in the macro-texture was also recorded. The surface friction of the polished sites was improved, but the length of time the improvement lasted varied significantly depending on surface characteristics and other factors.
Water cutting as a resurfacing treatment
Monitoring of macro and micro-texture data on continuous lengths of water cut surfaces has shown that in most cases the re-textured surface is returned to the condition of an unpolished surface. However, the rounded edges on chips cannot be restored to their original sharp angularity.

Water cutting polished surfaces extends resal lives, reduces the requirement for high PSV aggregate and reduces the frequency of rescaling due to polishing. Water cutting can leave road line marking untouched, thereby reducing the waste of non-renewable resources such as premium high PSV aggregate, binder and paint.

Until the discovery of this process, the primary treatment for a polished chipseal or asphalt surface was to resurface it. Normally this required resurfacing of the whole treatment length to ensure that the site surface friction was kept consistent. A polished surface means the aggregate had failed to provide the required skid resistance for the site, so an aggregate with a higher PSV would normally be used to reduce the rate of polishing of the surface. However if the correct PSV aggregate has been used, any polishing would be restricted to areas of highest stress or traffic scrub. These small areas may be easily treated with the water cutter.

UHP water cutting extends the life of surfacing material by refreshing the macro-texture and micro-texture when traditionally the site would be ressealed. The increase in surfacing life ranges from months to years depending on the site and cause of failure. Flushing in isolated areas on the Northern Motorway site caused failure in both texture (10m lengths with an average texture less than 0.5mm MPD) and skid resistance (10m sections below the threshold level). Previously the entire treatment length would have been resurfaced or burnt then resurfaced the following season. Water cutting was carried out only on the areas that were failing, representing only four percent of the total area of the traditional treatment length.

Variations in lifecycle
During the six years of UHP treatment of pavements to improve friction and texture deficient sites, the process has achieved significant improvement on all surfaces treated. However, on a very few sites the improvement has only been short term — months instead of years.

In most of the cases where the macro-texture has returned to pre-treatment levels within months of the treatment, the failure has been due to flushing caused by an unstable surface consisting of multiple layers of chip seal with a high binder to stone ratio. The reason for the re-flushing on these sites was that the excess binder continued to rise from below. While water cutting removes the excess binder from the surface it does not prevent more binder rising to refill the voids in the surface hence creating the need for subsequent water cutting treatments. In some of these cases the re-flushing has been expected and repeat water cutting treatment was programmed. Depending on the site conditions, a second treatment usually resulted in the extended life for the surfacing being realised. In some cases, UHP water cutting was seen as a temporary holding treatment while funding was obtained for a full rehabilitation for the site.

The variations in the lifecycle of the micro-texture improvement in a research project investigating the lifecycle of UHP watercutting polished road surfaces and other road trial sites are caused by a number of different factors that include:

Aggregates — Variations in source rock properties cause aggregates to polish at different rates and in different ways. These property variations are caused by the wide range of types of source rocks, including igneous, metamorphic and sedimentary. The size of the aggregates in the surfacing also affects the rate of polishing. Large stone chip seals are more prone to polishing because the tyres only touch the edges of the chip. As there are less large chips per unit area, the sharp edges become worn more rapidly, whereas with small stone chip seals there are more tyre-aggregate interactions so the polishing action is less severe.
On one of the trial sites, a chip seal was constructed using sealing chip from the same source rock but manufactured by a different quarry. Because of changes to chip geometry, the new chip polished within nine months.

Traffic — Levels of traffic on the trial sites vary from 500 vehicles per lane per day up to 14,000 vehicles per lane per day and a heavy vehicle count varying from 5% up to 23%.

Water cutting of a polished surface will not result in an improved wear rate unless the factors causing the initial polishing are reduced. Once the conditions are sufficient to cause an aggregate to polish, the aggregate will polish again.

Road surface geometry — Most of the sites that have polished are on tortuous alignments with short radius bends on steep grades, which causes extreme stress on the tyre aggregate interface resulting in polishing. Although PSV of the aggregates used on the sites complied with the TNZ T/10 (2002) requirements, the surfaces have polished. This indicates that the aggregate is not coping with the extreme polishing actions.

Climate — Most of the sites are affected by frosts and ice gritting practices in winter.

Cost
The cost of the UHP treatment per unit area is approximately double that of chip sealing and the lifecycle of the treatment is most likely less than that of a new chip seal. Comparing treatments purely on an area basis makes justification of water cutting as a resurfacing treatment more difficult. However there are a number of factors that should be included in the evaluation:

- only treating the areas that are flushed or polished stops the waste of non-renewable resources in sealing areas that do not require it
- the treatment is effectively rehabilitating the surface without the addition of new material (Figure 7) so it is more sustainable than resurfacing
- UHP treatment does not require aftercare signage or reinstatement of line marking. The effect of the process is immediate and line marking can be left untouched (Figure 8)
- may be used for removal of line marking, revitalisation of open graded porous asphalt surfaces, removal of spillages from road surfaces and rubber removal from airport runways
- it does not require any pavement preparation
- it does not use flammable solvents or hot bituminous products
- immediately after treatment, the site is available for normal use, minimising disruption to road users with no loose chips and related problems or reduced speed limits
- on some sites resurfacing a flushed or flushing chip seal with another chip seal adds more binder to the system. This will result in shortening seal lives leading to the site requiring more expensive treatments such as recycling or reconstruction. Water cutting to remove the excess binder is a viable option for most of these sites
- UHP water cutting may be carried out at any time of the day and is not weather dependent so the disruption to traffic flow is minimised.

Figure 7. Asphalt surface rejuvenation at Gladstone 2006

Note: Flushing on untreated section
Conclusions
UHP water cutting is an effective treatment for flushed and bleeding surfaces, although the life of the treatment is dependent on site conditions. It is a highly effective tool for improving the safety of road pavements that can be rapidly deployed in any season. The treatment may be applied to either large or small isolated polished sections.

Water cutting is an effective sustainable resurfacing treatment that reduces the use of non-renewable resources such as sealing chip, bitumen and road marking paint. The process can extend the life of a seal by improving both the micro and macro textures. Water cutting is an effective rehabilitation process that the pavement engineer can add to their toolkit.

References
1. BS EN 1097-8:2000 Tests for mechanical and physical properties of aggregates - Part 8: Determination of the polished stone value.

Acknowledgements
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