FIELD TRIALS IN CAIRNS FOR CONCRETE USING RECYCLED CRUSHED GLASS AS A FINE AGGREGATE REPLACEMENT

CASE STUDY

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Key Facts
• Australian produces 54 million tonnes of waste annually – 2.2 tonnes/person/year
• Cairns Regional Council crushes 7 – 10 tonnes of glass each operational day
• Three different concrete mixes containing different proportions of recycled crushed glass used to replace natural coarse sand (4 mm) were tested against a control
• Strength and workability optimum for 40% replacement. Negligible reduction in strength
• Total glass used in trial was 8.46 tonnes in 108 m of 2 m wide concrete footpath
• Significant economic savings

Need for Recycling is Increasing
Recycling is becoming an increasing issue due to rapid growth of population and industry. Closed loop recycling is the best sustainable method to re-use waste streams back into new production, as it creates energy savings, reduces the demand on primary mineral resources and diverts materials away from landfill. There is a need for the use of recycled glass in a way which promotes sustainability with economic, environmental and construction benefits.

In Australia, 54 million tonnes of waste was accumulated in 2018. That is equal to almost 2.2 tonnes per person per year and this figure is increasing every year. Glass accounts for almost one third of all recycled waste collected in Australia. Generally, 40% of the collected waste glass is recycled and the other 60% is crushed and sent to landfill. With high volumes of glass not being recovered, taking into account its non-biodegradable nature, there is increasing pressure to provide innovative solutions into the effective re-use of this material.

Local Government Requirements
The Cairns Regional Council (CRC) currently crushes recycled glass into a fine aggregate form (4 mm) as part of the kerbside recycling process at the Cairns Materials Recovery Facility (MRF). Approximately 7 – 10 tonnes of crushed glass is output from the MRF each operational day and material is readily available for concrete production upon completion of the crushing process. Its use in concrete would not only create significant

Figure 1 – Comparison of Crushed Glass and Natural Sand Particle Size and Shape
environmental benefits by reducing the amount of glass sent to landfill, but would also reduce the collection and transport costs and environmental effects associated with using natural sand. It is noted that there are small proportions of impurities in this raw material such as pieces of plastic, metal and paper.

The Cairns Regional Council expressed interest in utilising this recycled material in low risk infrastructure projects such as concrete pedestrian and cyclist footpaths. This application is suitable as kilometres of paths are being constructed every year due to the ever-increasing demand for pedestrian and cycle connectivity.

**Previous Studies**

In 2017 a laboratory study was undertaken at James Cook University Townsville in conjunction with the Cairns Regional Council. This study investigated the chemical and physical properties of waste glass; quantified pozzolanic properties of waste glass; verified the performance of concrete with waste glass as a partial replacement for fine aggregate and cement; and quantified economic and environmental benefits.

The results of this study ultimately showed that the use of recycled glass in concrete was beneficial as a fine aggregate replacement as it produced strength which was equal to or greater than a control mix, and also enhanced a range of other durability indicators. Replacement levels up to 60% replacement of natural sand were considered feasible with an optimal replacement level of 40%.

Although the laboratory results, as well as results from other literature, suggested the use of crushed glass could be feasible as a fine aggregate replacement, there have been limited field trials undertaken in order to assess how it performs. Key performance indicators include compressive strength, durability, workability, and quality of the finished surface.

**The Trial**

The trial undertaken by the Cairns Regional Council was located at the Progress Road entrance to the White Rock State School within the suburb of White Rock in Cairns, Queensland. An existing 1.6 m concrete footpath was located along the frontage of the school and needed replacement as it didn’t meet current standards and was in poor condition. The scope of works included the demolition of the existing footpath and the construction of a new 2 m wide compliant footpath of total length 108 m. The construction of the footpath was compliant to the Far North Queensland Regional Organisation of Councils (FNQROC) standard drawing S1035 – Pathways/Bikeways with the exception of the grade of concrete used. The FNQROC standard

![Figure 2 – Stockpile of Crushed Glass at Cairns Regional Council Materials Recovery Facility (MRF)](image)
specifies N25 grade concrete however N32 grade was used because the laboratory studies focussed on this grade.

A total of four different mixes were used in the trial, detailed below. Three mixes incorporated recycled crushed glass (RCG) to partially replace the natural 4 mm coarse sand and the fourth was a standard N class concrete used as the control mix. One of the three RCG mixes contained additional cementitious material to meet the Queensland Transport and Main Roads (QTMR) specification (MRTS70). Fine and coarse aggregates were sourced from local quarries in the Cairns region. All concrete mixes were supplied by Pioneer North Queensland (PNQ) who were a pivotal part of the preparation of this trial.

1. **RCG 40%**: 40% fine aggregate replacement mix – based on standard N32 class mix
2. **RCG 60%**: 60% fine aggregate replacement mix – based on standard N32 class mix
3. **RCG 40% TMR**: 40% fine aggregate replacement mix to QTMR Specification (MRTS70)
4. **Control**: Standard N32 class mix
Each RCG mix was 30 m in length and the control mix was utilised for a total of 18 m split over two sections. The three RCG mix designs were selected as there was sufficient laboratory data to confirm they were feasible to use in a field trial.

The compressive strength of each concrete mix was tested after 5, 7 and 28 days from the date of the pour. The characteristic strength for all mixes was 32 MPa. Target slump for each mix was 80 mm ± 15 mm. The works associated with the trial were undertaken over a nine-day period from Wednesday 9th January to Friday 18th of January 2019.

### Table 1: Slump Values for Each Mix

<table>
<thead>
<tr>
<th>Mix</th>
<th>RCG 40%</th>
<th>RCG 60%</th>
<th>RCG 40% TMR</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (mm)</td>
<td>80</td>
<td>100</td>
<td>90</td>
<td>80</td>
</tr>
</tbody>
</table>

### Table 2 – Compressive Strength for Each Mix and Comparison to Control

<table>
<thead>
<tr>
<th>Mix</th>
<th>RCG 40%</th>
<th>RCG 60%</th>
<th>RCG 40% TMR</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength after 28 Days (MPa)</td>
<td>33.1</td>
<td>25.9</td>
<td>28.5</td>
<td>34.0</td>
</tr>
<tr>
<td>Percentage Less than Control</td>
<td>2.6%</td>
<td>24%</td>
<td>16%</td>
<td>-</td>
</tr>
</tbody>
</table>

![Development of Compressive Strength - 5, 7 & 28 Days](image)

*Figure 4– Development of Compressive Strength for All Concrete Mixes Trialled*
Results

Workability
The workability of the concrete mixes was considered to be a key performance indicator. During the trial, contractors on site suggested that the 40% RCG TMR mix was the most similar to the control mix. The 60% RCG mix was least desirable as it was difficult to spread and screed. The 40% RCG achieved adequate workability however was more similar to the 60% RCG mix. All mixes trialled achieved the target slump range of $80 \text{ mm} \pm 15 \text{ mm}$ except for the 60% RCG mix. See Table 1.

Strength
The results of the compressive strength samples after 28 days of curing were consistent with those achieved in the laboratory study at James Cook University. Average results can be seen in Table 2. Figure 4 presents average compressive strength development over time. The 40% RCG mix was observed to achieve a compressive strength closest to that of the control mix after 7 and 28 days of curing. As with the laboratory study, the compressive strength of the 60% replacement mix was significantly lower than that of the control. Based on these findings it is concluded that a 40% replacement of fine aggregate with recycled crushed glass is optimal.

It is believed that with slight adjustments to the mix design of the Queensland Transport and Main Roads mix, the characteristic strength can be achieved. Further practical trials are suggested.

Finished Surface
The finished surface of the concrete footpath was another performance indicator as it is what the general public will notice the most. All of the concrete mixes in the trial were...
broomed finished. The method of assessment on the finished surface was by visual inspection after 28 days. The RCG 40% and RCG 40% TMR mixes resulted in finished surfaces which were similar to the control with the exception of small amounts of glass particles visible. The finished surface of the 60% RCG mix displayed a rough appearance and larger sized glass particles in some areas.

**Environmental**

The environmental analysis is the primary driver in assessing the benefits of recycled crushed glass as a fine aggregate replacement. This trial utilised 8.46 tonnes of recycled crushed glass which was the equivalent to almost 47000 glass bottles (based on a 355 ml glass beer bottle). On average there was 4.7 kg of glass per cubic meter of concrete, which was equivalent to 94 kg per meter of 2 m wide concrete footpath. Not
only was this amount of glass saved from being sent to landfill, the trial saved 8.8 tonnes of natural coarse sand (4 mm) from being used.

**Economic**

In addition to local governments desire to save money, two new initiatives are increasing the need for economic benefit even further. Commencing 1st July 2019, the Queensland Government is introducing a waste levee of $75 per tonne on all material sent to landfill. Additionally, with the commencement of the Queensland Container Refund Scheme (CRS) on 1st November 2018, local governments are eligible for a refund for glass containers collected through kerbside recycling which can be shown to have been recycled. Based on the amount of recycled crushed glass used in the trial, a saving of $635 in waste levy charges was achieved. An additional amount was refunded for the CRS.

The production cost of the four mixes, based on the amounts of raw material used, were all within $5 per cubic meter of each other. This is an attractive result as for negligible extra cost, acceptable levels of performance can be achieved while recycling significant amounts of glass.

**Limitations**

The use of recycled glass in concrete is suitable for broom finished concrete. Although exposed aggregate finishes have not been tested with concrete containing crushed glass, it is possible that glass particles may become loose and break away from the concrete during use. Other limitations include the use of glass in concrete in higher risk applications such as structural members or load bearing applications such as culverts.

**The Outlook**

Close monitoring of this trial footpath by the Cairns Regional Council is required to determine if the use of recycled glass in concrete affects short and long term durability. Currently after five months, there are no visual signs of increased wear on the concrete containing glass compared to the control.

The 40% RCG mix was the most suitable mix in the trial to satisfy the requirements of the Cairns Regional Council as it achieved acceptable strength and workability. The Queensland Transport and Main Roads mix requires slight adjustment and further trials before it may be suitable for use. It is expected that with refinements to this mix, the characteristic strength can be achieved.

With the success of this trial with regards to compressive strength, workability, and environmental and economic enhancements, it is anticipated that more footpaths trials will be undertaken in the Cairns region in the future. With more pressure for innovation and improvements in the public works sector, as well as increasing need for recycling and reuse, the use of recycled glass in concrete is becoming very appealing. If large stockpiles of glass which is already crushed into the appropriate size can be reduced at the rate of 4.7 kg per cubic meter of compliant concrete, and economic benefit can be sought from the container refund scheme and avoidance of waste levee, it is difficult to see why local governments would not utilise this resource. The result of this trial shows glass can be recycled in a way which promotes sustainability with economic, environmental and construction benefits.