The effect of adding recycled glass on the performance of basecourse aggregate
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An important note for the reader

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the NZ Transport Agency is to undertake its functions in a way that contributes to an affordable, integrated, safe, responsive, and sustainable land transport system. Each year, the NZ Transport Agency invests a portion of its funds on research that contributes to this objective.

This report is the final stage of a project commissioned by Land Transport New Zealand before 31 July 2008 and is published by the NZ Transport Agency.

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The material contained in this report is the output of research and should not be construed in any way as policy adopted by the NZ Transport Agency but may be used in the formulation of future policy.

Additional note

The NZ Transport Agency (NZTA) was formally established on 1 August 2008, combining the functions and expertise of Land Transport NZ and Transit NZ.

The new organisation will provide an integrated approach to transport planning, funding and delivery.

This research report was prepared prior to the establishment of the NZTA and may refer to Land Transport NZ and Transit NZ.

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Abbreviations and acronyms

AASHTO	American Association of State Highway and Transportation Officials
ASR	Alkali-silica reaction
ASTM	American Society for Testing and Materials
CalTrans	California Department of Transportation
CAPTIF	Canterbury Accelerated Pavement Testing Indoor Facility
CBR	California bearing ratio
DOS	Degree of saturation
HMA	Hot mix asphalt
MDD	Maximum dry density
MnDOT	Minnesota Department of Transport
NHDOT	New Hampshire Department of Transportation
O-I Ltd	Owens-Illinois Ltd (formerly ACI Glass)
OMC	Optimum moisture content
PSD	Particle size distribution
RLT	Repeated load triaxial
Transit NZ	Transit New Zealand (now NZ Transport Agency)
UCS	Unconfined compressive strength
WSDOT	Washington State Department of Transportation

Contents

Executive summary

This research project used the repeated load triaxial (RLT) test and associated rut depth modelling to assess the effect on performance/rut resistance of adding various percentages by mass of recycled crushed glass to a basecourse aggregate. The aim was to determine a maximum percentage of recycled glass that could be safely added to an aggregate used as a basecourse without impairing its performance. Research has been undertaken overseas on the addition of glass to aggregate for use as a basecourse and asphalt. From the literature review it was found that most specifications allowed up to 15% by mass of crushed glass to be added to the basecourse aggregate.

The laboratory study involved testing the same aggregate with a range of percentages of crushed glass of 0%, 10%, 20%, 30% and 50%. Adding glass in quantities > 20% moved the final grading of the aggregate glass mixture outside the limits of the TNZ M/4 specification (Transit NZ 2006). However, the performance of the basecourse was observed to improve with increasing percentages of crushed glass up to 30% (see figure E1).

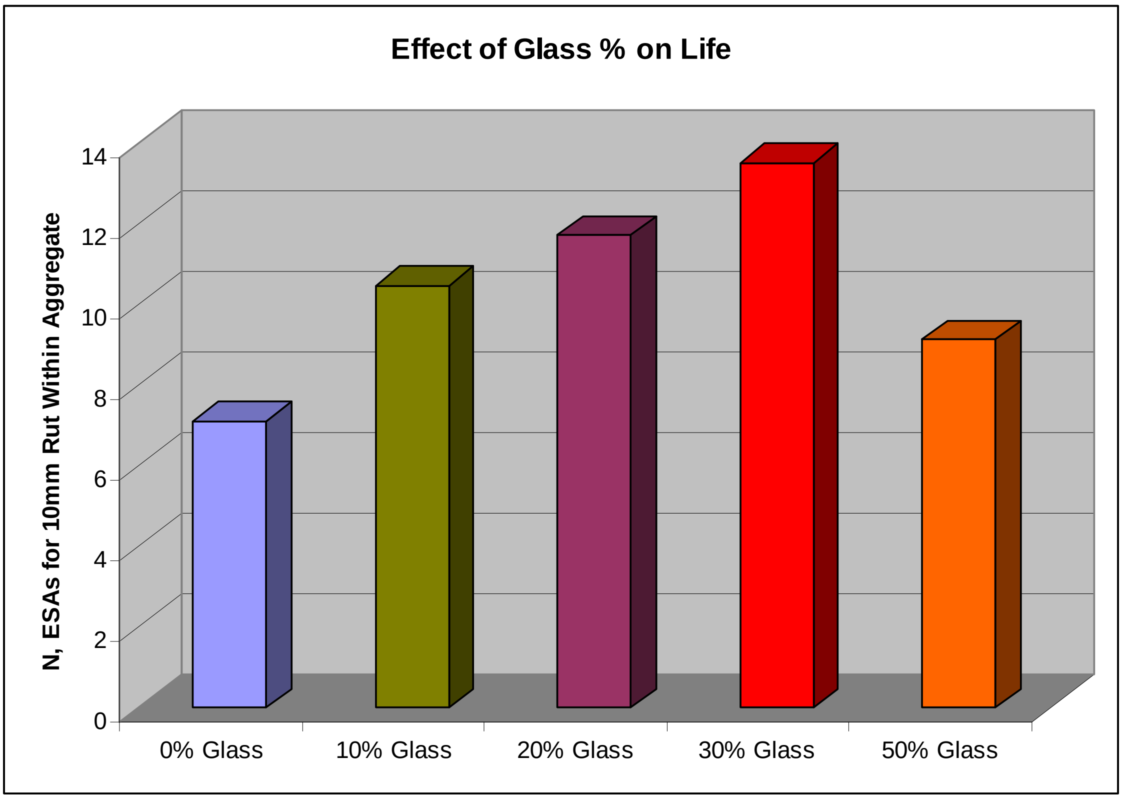

Figure E1 Effect of glass content on a number of load cycles to achieve a 10 mm rut within aggregate layer for the Pavespec RLT test results.

Based on the RLT test results it appeared that adding crushed glass in quantities of up to 30% by mass had little or no effect on aggregate rut depth performance. The material used was an already high rut resistant aggregate from Pound Road Quarry in Christchurch. The result was surprising considering 23% of the aggregate was crushed glass less than 9.5 mm in size. Further

RLT tests by Pavespec Ltd on aggregate from Pound Road Quarry in Christchurch confirmed this result.

Given that the literature generally shows crushed glass up to 15% by mass is acceptable for basecourse aggregates and the triaxial study showed little effect on aggregate performance, this study recommends that 15% be used as the new limit for crushed glass in basecourse. Further, the grading envelope for the glass cullet should be expanded to reflect the aggregate used in this study, as typical of what would normally be crushed. Higher percentages may be accepted if proven through RLT testing.

Abstract

Glass bottles collected by councils are forming large stockpiles, particularly in the South Island, as it is uneconomic to transport the glass to the Auckland plant for recycling. An alternative method of disposal would be to crush the glass and mix it into basecourse aggregate. NZ Transport Agency currently allows up to 5% by mass of crushed glass to be mixed in the aggregate. This study investigated the effect on aggregate performance of percentages of crushed glass up to a maximum of 50% by mass of aggregate or a third of the total mass. Performance was measured using the repeated load triaxial apparatus and associated rut depth modelling to determine the number of heavy axles until 10 mm of rutting occurred within the aggregate layer. Results found that the performance of the aggregate was not affected for percentages of crushed glass up to 30% by mass of aggregate or 23% of the total aggregate.

1. Introduction

The vast quantities of waste (such as scrap tires, glass, blast furnace slag, steel slag, plastics, construction and demolition wastes) accumulating in stockpiles and landfills throughout the world are causing disposal problems that are both financially and environmentally expensive. The environmental consciousness of governments and the public is causing more difficulty in disposing of these materials, particularly where restrictive provisions discourage or even prohibit them from being placed in sanitary landfills.

Dealing with the growing problem of disposal of these materials is an issue that requires coordination and commitment by all parties involved. One solution to a portion of the waste disposal problem is to recycle and use these materials in the construction of highways. However, such a use should not compromise the quality and performance of the highway infrastructure nor create an environmental problem.

Research into new and innovative uses of waste and recycled materials as potential roading materials is continually advancing. In Europe, the United States and Canada many highway agencies, private organisations and individuals have completed, or are in the process of completing, a wide variety of studies concerning the feasibility and environmental suitability of using recycled products and their resulting performance in highway construction. These studies try to match society's need for safe and economic disposal of waste materials with the highway industry's need for better and more cost-effective construction materials. However, nominal research has been done in New Zealand on the availability of feasible waste materials and to determine if these materials would be suitable for New Zealand roads. Yet the use of these materials would benefit the roading industry by providing it with an alternative source of material. In some cases, road construction companies might be able to charge a fee for using waste materials that would otherwise require disposal.

NZ Transport Agency has developed a practical repeated load triaxial (RLT) test to categorise the suitability of pavement materials as base materials for high, medium or low traffic situations in either dry or saturated conditions (Arnold et al. 2008). The RLT can be used to assess a range of materials including marginal materials (previously discarded) to determine where they can be used (eg in low traffic and dry environments). Alternative materials, eg industrial by-products such as melter slag and waste materials (eg glass and recycled crushed concrete) can also be assessed and used appropriately according to their level of rut resistance in wet and dry conditions.

RLT tests along with associated rut depth modelling (Arnold et al. 2008) were used to assess the effect on performance/rut resistance of adding various percentages by mass of recycled crushed glass to a basecourse aggregate. The outcome has been a recommended maximum percentage of recycled glass that can be safely added to an aggregate used as a basecourse without impairing its performance. Research has been undertaken overseas on the topic of adding glass to aggregate, although it is considered valid only for materials covered by at least 100 mm of structural asphalt or good quality aggregate and used as a subbase only. Basecourse aggregates used under a thin surfaced chip seal suffer higher tyre stresses and require careful selection.

1.1 Background

The only facility offering closed loop recycling of glass in New Zealand is Owens-Illinois Ltd (O-I Ltd) (formerly known as ACI Glass) in Auckland. Even before the much publicised 2005 fall in cullet prices, it was debatable whether it was financially worthwhile sending glass from the South Island to Auckland. Transport costs are simply too high compared with the product value and when the labour to sort and meet the quality requirements is factored in, many jurisdictions have found it uneconomic to use this recycling option. With the fall in prices (particularly for flint), recycling through Auckland became even more uneconomic. Publicity elicited negative public comment, especially as so many householders were going to the trouble of recycling their bottles. The perception was that their effort was for nought. Much to its credit, the Packaging Council of New Zealand organised a voluntary levy on imported glass to subsidise the transport of flint glass to Auckland for recycling. This was to run for a period of six months; it was hoped that during this time an initiative would emerge to recycle the glass in alternative ways. This period has expired. The government has been observing the situation and has made no secret of the fact that it expects industry to find voluntary methods to ensure a continuation of glass recycling. If this does not occur, government has reserved the right to use legislative tools to oblige brand-owners/ packagers to adopt extended producer responsibility.

The benefits of using glass incorporated into basecourse aggregate are that colour separation is not necessary; glass can be processed and used locally; large quantities can be absorbed sustainably; local authorities or their contractors do not have to invest in any equipment; the development of alternative high-value uses is not discouraged; and expensive landfilling and ad hoc stockpiling of glass can be eliminated.

1.2 Objectives

The objective of this research project was to:

- determine acceptable percentages of recycled glass that could be added to a basecourse aggregate used under a thin surface typical of New Zealand roads, without reducing its performance/rut resistance.

2. Literature review

2.1 Introduction

Glass is an important industrial material, with its main uses in glazing and packaging of foodstuffs. New Zealand consumes an estimated 250,000 tonnes of glass each year, about 185,000 tonnes of which is container glass (bottles and jars). Glass consumption has increased significantly over the past decade and continues to trend upwards (Thomas 2005). O-I Ltd, New Zealand's only commercial glass container manufacturer supplies about 64% of the total domestic market. O-I Ltd can manufacture glass bottles and jars ranging from 250 ml to 1 litre. Other distributors and brand owners import the remaining 36% or 68,000 tonnes. This is mainly wine bottles (from Europe), soft drink bottles (from the Middle East) and beer bottles (from Asia). O-I Ltd announced in late 2004 that it would reduce the price it paid to purchase used glass (cullet). Thomas (2005) reported that pricing would fall to around $10/tonne for flint (clear) cullet and $75/tonne for green or amber cullet. In addition, several glass collectors reported 70% rejection of shipments due to colour or other contamination.

These decisions have had a significant impact on glass collection, particularly in the South Island, where the lower cullet prices plus increasing transportation costs make it uneconomic to ship cullet to Auckland for recycling. This has led to many South Island areas stockpiling recovered glass in anticipation of future markets.

Nelson currently has an annual glass collection of just over 1000 tonnes which is sent to Auckland. In the light of the recent price decline, the council is very keen to reroute its glass to a local recycling option. In line with other districts, glass volumes are expected to grow with development and are trending upwards (Thomas 2005) though this has not been quantified. One thousand tonnes of glass will, therefore, equate to 1000 tonne savings in aggregate or $40,000 (assuming $40 per tonne for South Island aggregate), although it is expected that there will be no financial savings due to the cost of crushing and adding glass. Therefore, the main savings would be landfill charges.

A literature search was undertaken using the resources of the Engineering Library at the University of Canterbury, and also the internet, for information on the use of recycled glass (or glass cullet) in roads. The Transportation Research Board in the United States was found to have the most published papers on the use of glass, while other internet sites detailed specifications on acceptable limits of the use of glass. Several uses of glass were found in roads, namely: asphalt, mixtures of glass and crushed rock for basecourse aggregate, drainage aggregate and foamed glass as an insulating layer in pavements located in frost-prone areas.

2.2 Glass recovery in New Zealand

The Packaging Council of New Zealand annually tracks recovery levels and trends of packaging waste to landfill. The collation of the data is a key part of the Packaging Council's commitment to the Packaging Accord (2004) which sets out targets for packaging recovery by 2008. Table 2.1 charts progress by packaging type and against the accord targets.

Table 2.1 Packaging recovery rates in New Zealand (Packaging Council, 2005 data).

Material	Prod	Consm	Rcvd	2003	2004	2005	2008
	(tonnes)	(tonnes)	(tonnes)	(%)	(%)	(%)	Target
Aluminium	8910	5655	3460	62	61	61	65
Glass	128,905	189,005	92,825	48	50	49	55
Paper	520,090	293,315	209,925	69	72	72	70
Plastic	171,365	145,650	31,310	19	20	21	23
Steel	42,115	39,465	12,120	36	35	31	43
Total	871,385	673,090	349,640	51	53	52	

Market changes continue to make the glass target of 55% recovery by 2008 a challenge. This is compounded by co-mingled collections in Waitakere and North Shore where around 30% of the glass collected is no longer suitable for use by O-I Ltd. There is a concern that more councils may make the move to co-mingled collections resulting in an increasing amount of glass which is simply rendered unsuitable for glass container making.

2.3 Glass in asphalt

Asphalt with glass cullet is commonly referred to as 'glasphalt' which contains up to 30% of glass cullet as replacement aggregate. Glasphalt is used in the structural layers of the pavement below the surfacing layer to prevent the problems that occur when it is used as a surfacing asphalt. These include lack of skid resistance and poor bonding of glass cullet to the bitumen in the asphalt mix, which results in stripping and ravelling problems. In general, waste glass contains impurities such as ceramics, ferrous metal, paper, plastic and mixed coloured cullet which can also cause ravelling and stripping. However, controlled processing and specification limits can reduce or eliminate these problems.

Several laboratory and field evaluations of glasphalt were conducted in the early 1970s in the United States and Canada. After no significant interest for a decade, the potential use of glasphalt is now being reassessed. Three states – Connecticut, Virginia and Florida – have conducted feasibility studies (Kandahl 1992). The Connecticut report gives an excellent review of literature on both laboratory and field evaluations of glasphalt since 1969 and found:

- Glasphalt was successfully mixed and placed in at least 45 locations in the United States and Canada between 1969 and 1988. However, most glasphalt has been placed on city streets, driveways and parking lots, and not on high-volume, high-speed highways.

- Potential problems with glasphalt include: loss of adhesion between asphalt and glass; maintenance of an adequate level of skid resistance, especially with coarse particles; breakage of glass and subsequent ravelling under studded tires; lack of adequate and consistent supply of glass; and increased production costs (estimated at $5/tonne more than the conventional hot mix asphalt (HMA) in Connecticut).
- Glasphalt should be used only as a basecourse as glass in the surfacing mixture could reduce skid resistance and create surface ravelling problems.
- The maximum size of glass used in glasphalt is 9.5 mm and hydrated lime should be added to prevent stripping.

The Virginia report is based on laboratory evaluation and economic analysis of glasphalt. Two glass contents, 5% and 15%, and two asphalt contents were used in the laboratory evaluation of Virginia S-5 surface HMA mix (12.5 mm top size). A densely graded recycled glass with a maximum nominal size of 9.5 mm was used. The following are significant conclusions:

- The use of glass tends to reduce the voids in the mineral aggregate and air voids in Marshall specimens, therefore, optimum asphalt content will also be reduced.
- Neither resilient modulus nor indirect tensile strengths are adversely affected by the addition of up to 15% glass.
- Although both wet strength and retained tensile strength ratios (TSR) were unaffected by the percentage of glass, some separation at the asphalt/glass interface was observed.
- A maximum of 15% crushed recycled glass should be allowed (100% passing a 9.5 mm sieve and a maximum of 6% passing a 75 μm sieve) in HMA mixes.
- There is little monetary incentive to use recycled glass at the present time because the cost of glass varies considerably.
- An experimental section should be laid prior to extensive use of waste glass.

The Florida Department of Transportation tested three HMA mixtures to determine the effects of crushed glass. AC-30 asphalt cement with and without antistripping agent was used to prepare Marshall specimens which were also tested for tensile strength. The following conclusions were drawn based on the limited laboratory evaluation:

- Marshall stability values decreased by 15–20% and dry indirect tensile strength decreased by 20% when 15% of the screenings were replaced with either coarse or fine glass.
- Moisture conditioning of Marshall specimens caused a 15% and 50% decrease in tensile strength when coarse and fine glass, respectively, were incorporated into the mixture. Retained tensile strength ratio values indicated that the antistripping additive was ineffective in reducing the moisture damage.
- It is unlikely that the use of crushed glass in HMA mixtures will be economically feasible when suitable local materials are available at or near the HMA facility.

More recently, numerous paving projects using waste glass have been undertaken around the United States. However, by far the most aggressive programme has been undertaken by the City of New York's Department of Transportation, where from 1990 through 1995 approximately 225,000 metric tons (250,000 tons) of glass were used in resurfacing applications (http://tfhrc.gov/hnr20/recycle/waste/wg2.htm).

The Federal Highway Administration's Turner-Fairbank Highway Research Center in Washington DC reported that satisfactory performance had been obtained from HMA pavements incorporating 10 to 15% crushed glass in wearing surface mixes. Higher blends, up to 25%, could potentially be used in base or binder course mixes. HMA surface course pavements with more than 15% waste glass may experience deterioration due to stripping of the asphalt cement binder from the waste glass.

Cemex, a construction company in the United Kingdom, reports on its website (www.cemex.co.uk/page.asp?id=2918) that glasphalt is a coated macadam containing up to 30% crushed glass that may be used as a base or binder course asphalt. It is intended only for use in the structural layers of a pavement, as glass cannot exhibit the necessary skid resistance due to its propensity to polish quickly. Glasphalt has undergone a rigorous and independent testing programme and this has concluded that the material can be manufactured with up to 30% of the aggregate being replaced by crushed glass without any detrimental effect on the properties of the mix.

Mechanical properties of the asphalt mixtures with and without glass cullet were measured at the Nottingham Centre for Pavement Engineering (Airey et al. 2004) using the Nottingham asphalt tester to conduct a suite of tests (stiffness modulus, resistance to permanent deformation and resistance to fatigue cracking). The durability of the primary and secondary mixtures was assessed by subjecting the materials to simulative long-term laboratory aging and moisture susceptibility conditioning using recognised testing (conditioning) procedures and protocols. The results indicated that the use of glass cullet fine aggregate in a 28 mm continuously graded asphalt base material only marginally reduced the stiffness modulus of the secondary aggregate modified mixture. The moisture susceptibility of the material was also shown to be less than would be expected for a smooth surface textured aggregate such as glass, with and without the use of an anti-stripping agent. The replacement of primary aggregate with glass cullet also significantly reduced the aging susceptibility of the mixture, while the permanent deformation resistance, although inferior to that of a primary aggregate mixture, was still acceptable with the fatigue performance being comparable to the control mixture.

2.4 Glass in aggregate

As crushed glass is of similar strength to crushed rock in basecourse, several road controlling authorities have allowed percentages of crushed glass to be added to the basecourse aggregate. At present, the Transit NZ (2006) specification for basecourse aggregate (TNZ M/4) allows 5% by mass of crushed glass (<9.5 mm) to be added to the source aggregate with no adjustment in grading necessary. This change was based on international use where generally quantities of up to 15% are considered acceptable. A conservative 5% was chosen, as basecourses in New Zealand are only covered by a chipseal compared with the Northern Hemisphere where the basecourses are protected by at least 100 mm of structural asphalt.

MnDOT (Minnesota Department of Transport) has developed an engineering specification for using glass waste in basecource aggregate (Hyman and Johnson 2004). The specification allows the addition of this material to granular aggregate at no more than 10% by mass. In addition, the specification restricts debris (eg bottle caps, paper and plastic) to 5% of the total glass volume.

The Turner-Fairbank Highway Research Center recommends that 'crushed waste glass (cullet) used in granular base applications should be limited to the replacement of fine aggregate sizes [less than 4.75 mm]. Crushed glass … will perform as a highly stable (angular) fine aggregate material. It has been recommended that maximum cullet content should be limited to 15% in granular base applications and 30% in subbase applications (http://tfhrc.gov/hnr20/recycle/waste/wg3.htm).

Shin and Sonntag (1994) undertook in Washington DC a comprehensive study of varying percentages of crushed glass (0, 15, 50 and 100%) and aggregate for a range of construction applications. A range of tests were conducted including: compaction tests, gradation, California bearing ratio (CBR) and elastic RLT tests. The study showed that glass, as an aggregate, is strong, safe, clean and economical to use from an engineering standpoint provided percentages of glass and debris (contaminants in glass) are below the limits in tables 2.2, 2.3 and 2.4.

Table 2.2 Application specification for structural uses of aggregate and glass mixtures (Shin and Sonntag 1994).

Gradation of glass fraction					
Sieve size (mm)	**% passing by weight**	**Use**	**Max. glass content (%)**	**Max. debris level (%)**	**Min. compaction level (%)**
19.0	100	Basecourse	15	5	95
6.3	10–100	Subbase	30	5	95
1.9	0–50	Embankments	30	5	90
0.425	0–25	Nonstructural fill	100	10	85
0.075	0–5	Utility bedding and backfill	100	5	90

Table 2.3 Application specification for drainage fill using aggregate and glass mixtures (Shin and Sonntag 1994).

Gradation of glass fraction					
Sieve size (mm)	**% passing by weight**	**Use**	**Max. glass content (%)**	**Max. debris level (%)**	**Min. compaction level (%)**
19.0	100	Retaining walls	100	5	95
6.3	10–100	Foundation drainage	100	5	95
1.9	0–100	Drainage blankets	100	5	90
0.425	0–50	French drains	100	5	90
0.075	0–5				

Glass cullet appears to be an excellent supplement or replacement for natural aggregates in many construction applications. Finkle et al. (2007) studied the strength and moisture/density characteristics of different glass and aggregate blends to examine the effects of blending glass cullet into basecourse aggregate. Two sources of natural aggregate were tested, one being crusher run and very angular in nature and the other being pit run and rounded in nature. The glass was introduced into the aggregate at replacement rates of 10%, 20% and 30%. Four different maximum glass cullet sizes were also tested, with maximum sizes ranging from ¾ inch (19 mm) to ⅜ inch (9.5 mm). The strength of the glass-aggregate blends was evaluated using the American Association of State Highway and Transportation Officials (AASHTO) T190–Resistance R-value test. Analysis of the data showed that glass cullet, mixed with the more angular crusher run aggregate (LAF), performed more consistently than when the cullet was combined with the rounded natural aggregate (STAR) for all sizes and replacement rates. The LAF glass-aggregate blends had average strength values above or slightly lower than the control mix across all replacement rates and maximum cullet sizes. The STAR blends exhibited a decrease in strength as both cullet size and replacement rate increased. The moisture-density relationships were determined in accordance with the AASHTO T99 standard Proctor test. The maximum size of glass cullet used was shown to be insignificant in determining the optimum moisture content and maximum density of the blends. The replacement rate had a significant effect on both compaction properties. As the cullet content increased the optimum moisture content increased and the maximum density decreased.

Embankments in the transportation infrastructure use large quantities of good and marginal quality aggregate materials and are, therefore, good applications for possible use of waste materials such as glass. Senadheera et al. (2007) investigated the resilient characteristics of a blend of caliche, a marginal quality granular material, which is typically used in low traffic volume pavement subbase layers and glass cullet. The authors conducted resilient modulus tests on a series of specimens containing different caliche-glass cullet blends. Resilient modulus of granular material depends on factors such as aggregate mineralogy, particle characteristics, density, moisture content and gradation. However, when a material blend is used in addition to the factors indicated above, the material response appears to depend also on relative strengths and compatibility of constituent materials in the blend. The general acceptance has been that by blending glass cullet with conventional materials, its engineering properties, particularly the strength, decreases. However, results from resilient modulus tests indicated that for marginal quality granular materials such as caliche, the introduction of glass cullet increased the strength of the material blend. However, the gain in strength appeared to be accompanied by a likelihood of the material failing by dilation at higher stress levels. As long as the caliche-glass cullet blend was not subjected to excessive stress levels, the presence of cullet in the blend appeared to strengthen the resilient properties of the granular material.

2.4.1 Specifications allowing glass in aggregate

The United States has the greatest number of specifications allowing the use of glass in aggregate and are summarised below.

The Washington State Department of Transportation (WSDOT) permits the use of recycled glass as an additive up to 15% to unbound aggregate used for 17 specific applications, including a number of fill and ballast uses. No more than 10% of the glass should be retained on a 6.4 mm sieve. WSDOT also provides specifications for construction aggregates composed entirely of cullet. These aggregates may be used for wall backfill, rigid and flexible pipe bedding, drainage backfill, drainage blanket, and gravel borrow. The cullet must be smaller than ¾ inch (19 mm) and should contain no more than 5% by weight of material finer than a 0.075 mm sieve. The maximum debris content, including all non-glass constituents, is 10% as identified by visual methods. In addition, the glass supplier must test the total lead content of the cullet on a quarterly basis according to Environmental Protection Agency methods 3010/6010. The mean of these tests cannot exceed 80 parts per million lead.

The Oregon Department of Transportation has issued special provisions with bid specifications allowing the use of up to 100% recycled glass in a number of applications: drainage blanket, utility bedding and backfill, and subsurface drains. One hundred percent of the glass must pass a 12.7 mm sieve, with a maximum of 5% by weight finer than 200 mesh. Maximum debris content is 5% or 10%, as specified per application, determined by visual classification.

The California Department of Transportation (CalTrans) has accepted cullet specifications for Classes 1, 2, 3 and 4 base and Classes 2 and 3 subbase roadway aggregate for the support of flexible and rigid pavements. These aggregates can consist entirely of cullet, or a mixture of cullet and other reclaimed materials, such as asphalt concrete, cement concrete, lean concrete base and cement treated base. The different classes of base and subbase aggregate are distinguished by gradations. The size of the cullet used must follow the size criteria specified for those aggregate applications by CalTrans. Material used in these base and subbase aggregates must be free of organic material and other deleterious substances. Surfacing material must be placed over all aggregate bases and subbases containing glass cullet.

The State of Connecticut specifies that aggregate used for roadway embankments may contain up to 25% by weight of cullet smaller than one inch (25 mm). Aggregate containing cullet cannot be placed within five feet from the face of any slope.

The New York State Department of Transportation allows aggregate for embankments to contain up to 30% by volume of glass cullet. In addition, roadway subbase material may contain up to 30% by weight of glass cullet. Cullet used for these applications must be smaller than ⅜ inch (9.5 mm), and should contain no more than 5% by volume of ceramics and non-glass materials, based on visual inspection. Waste glass cannot be placed in contact with any synthetic liners, geogrids or geotextile material.

The New Hampshire Department of Transportation (NHDOT) allows glass cullet to replace 5% by weight of the dry aggregate used for roadway basecourse material. The material used to produce this cullet should consist primarily of recycled food and beverage glass containers. Small amounts of ceramics and plate glass are also permitted, although glass containing hazardous or toxic materials is not allowed. The cullet must be smaller than ½ inch in size, and not more than 1.5% of the material smaller than a 4.75 mm sieve should be smaller than a 0.075 mm sieve. NHDOT requires that all basecourse be tested for compliance with this gradation prior to placement. Post-placement visual inspection of the basecourse is also required. Basecourse containing cullet must be capped with non-cullet aggregate before the public is allowed to drive over the material.

In December 2000, AASHTO adopted a new national specification, M 318-01 Glass cullet use for soil aggregate base course (AASHTO 2000) for recycling glass in soil aggregate basecourses. Up to 20% glass cullet is routinely allowed to be mixed with aggregate basecourse. However, the glass cullet is required to be at least 95% container/beverage glass to limit the use of other glass-like ceramics. There is a requirement to check that the resilient modulus from RLT testing and CBR is not affected/reduced due to the addition of glass. The engineer may also allow higher percentages of glass cullet provided the CBR and resilient modulus does not reduce. For safety requirements AASHTO requires 99% of the glass cullet to pass the 4.75 mm sieve.

2.5 Glass with cemented aggregates

A 1974 American Society for Testing and Materials (ASTM) study proved that glass with cement and aggregate causes an alkali-silica reaction (ASR) (Ahmed 1993). The reaction between glass and cement causes an expansion of glass which reduces the strength of the concrete. The workability of the concrete mix is also affected due to the elongated particles typical of glass cullet.

Due to the reaction between cement and glass, CalTrans (Ahmed 1993) prohibits the use of glass as an aggregate substitute in Portland cement concrete, cement-treated base, lean concrete base and cement-treated permeable base.

However, the major drawback of glass is that the alkali in the cement can react with the silica in the glass. ASR produces a gel on the aggregate surface which swells and can cause the concrete to crack. In the United Kingdom the concrete industry has avoided using glass as an aggregate, particularly as the ASR may take several years to manifest itself. However, recent work in the United Kingdom has demonstrated that ASR can be avoided by either using a fine-sized glass aggregate, less than about 1 mm, or by suppressing the reaction with admixtures or using a low-alkali cement. Other work has shown that with additions of very fine glass powder (<45 microns) the glass undergoes pozzolanic reactions, which have the potential to increase the concrete strength. The uses of glass aggregates in concrete are being investigated by two WRAP-funded projects, one at the University of Dundee and one at the University of Sheffield (ENVIROS 2003).

2.6 Glass beads in roadmarking paint

Recycled glass is used by Potters Industries of Australia for the manufacture of high-quality glass beads for road marking. The glass beads are added to road-marking paint to enable the lines to be seen at night by reflecting light from car headlights. The product is used in both Australia and New Zealand. In 2005, Potters Industries contacted Wastebusters to source 10,000 m^3 of clear/flint glass per year – including bottle glass, drinking glasses and window glass, with a long-term contract to supply. Russell Pieper, the Manager of Potters Industries, gave a seminar in New Zealand in April 2005 where he detailed the company's fairly stringent requirements.

Trials are now taking place to look into the practicalities of crushing the glass and shipping it to South Australia. At this stage, Terranova has expressed an interest in looking into the proposal; Hurunui Recycling are investigating the costs and practicalities involved; as are Wastebusters Canterbury, who have sent an initial container load to Australia – ironically the old glass milk bottles from Meadow Fresh. Wastebusters is also currently in the process of leasing some glass-crushing equipment and will soon be carrying out trials for financial evaluation. Hurunui will need supplies of glass additional to their own to make the scheme viable.

2.7 Foaming waste glass

Foamed glass is a lightweight, opaque glass material having a closed-cell structure. It is made in moulds that are packed with crushed or granulated glass mixed with a chemical agent such as carbon or limestone. At the temperature at which the glass grains become soft enough to cohere, the agent gives off a gas that is entrapped in the glass and forms the closed-cell structure that remains.

The manufacture of foamed glass is a process for waste recycling on an industrial basis. Foam glass can be manufactured fully out of waste glass, with only a minimum of virgin additives.

Foamed glass grain can be used wherever a finely grained, free-flowing bulk material is required. It is especially suitable for light-weight embankment fill (density of around 0.3 t/m^3) and thin-walled thermal insulations, such as for window frames, cement bricks and insulating plasters. Other uses are:

- road construction: lightweight bulk material with excellent drainage properties
- pile foundation
- building insulation
- trench filling material with high compression strength
- stabilising of slipping soil
- insulation of sports grounds
- insulation of swimming pools
- roof insulation.

Research in Japan (Onitsuka and Shen 1999) evaluated lime-stabilised clay with foaming waste glass as a pavement material. They found the CBR of the coarser foaming waste glass (2.00 mm to 4.75 mm particle size) was 31% and the unconfined compressive strength (UCS) was 3.5 MPa. Mixtures of coarse foaming waste glass (10, 15, 20 and 25%) and lime (5, 10, 15 and 20%) stabilised clays at 7- and 28-day curing periods were tested in the laboratory. The highest values recorded were a UCS of 1.8 MPa and CBR of 72% – these were for the clay mixture with the greatest quantities of foamed glass and lime used in this study.

2.8 Other uses of glass

In Minnesota some landfills accept broken glass as daily cover at a discounted cost because broken glass is rather innocuous and resembles aggregates (Hyman and Johnson 2004).

Crushed glass as a backfill material around drainage pipes was used in a demonstration project in Bruceville, Indiana (Siddiki et al. 2004). The type of crushed glass used was comparable to INDOT B borrow (granular fill) as in INDOT standard specifications. For 100% crushed glass to be used as bedding material, the following is required: (a) the source of the crushed glass should be glass beverage and food containers that have been processed by equipment specifically designed to crush glass into aggregate; (b) the resultant material must be relatively free of bottle caps, labelling paper, clay balls and other unsuitable materials; and (c) 100% crushed glass must have particle size gradations as indicated in table 2.4. On the basis of both construction data and recent observations of the site, the embankment and pavement continue to perform well.

Table 2.4 Glass grading requirements for drainage and bedding material (Siddiki et al. 2004)

Sieve	% Fines
12.5 mm (1/2 in.)	85 to 100
4.75 mm (No. 4)	45 to 85
2 mm (No. 10)	25 to 70
0.425 mm (No. 40)	10 to 30
0.075 mm (No. 200)	0 to 10

Foamed glass has also been used as an insulating layer over the subgrade in frost prone areas subject to freeze thaw cycles (Kestler 2004). The United Kingdom has approval to use up to 10% glass in their 'Foamix' bound subbase product (ENVIROS 2003). These applications for glass are being developed by the United Kingdom's largest construction companies, Tarmac and Lafarge.

2.9 Economics of using glass in roads

The Glass Packaging Forum funded a cost-benefit analysis which found that the premium for processing aggregate with glass cullet over conventional mineral aggregate is around $2 per tonne but this extra cost has not been recognised in most tenders. An amended Transit NZ road specification introduced this year now allows for the use of up to 5% of glass cullet in the basecourse for roading. This will help provide a local answer for many communities who find that the cost of sending glass back to Auckland for processing is too high. However, at present this is not economically viable unless councils also put the potential cost of landfilling the glass into the equation.

The Packaging Council has assisted two local communities in Palmerston North and Nelson with funds to trial crushing glass in a mix with traditional mineral aggregate. It was found that whether glass is crushed separately and mixed later with rock or crushed together with rock, the costs are broadly similar. However, the glass cullet/aggregate blended product costs around $2 per tonne more than a conventional mineral aggregate. This effectively means that using 5% glass cullet in the mix may cost up to 30% more. Using glass locally in roads is economically viable if a whole of life approach is adopted. The savings in landfill costs will outweigh the extra costs of using glass in basecourse aggregate.

MnDOT (Hyman and Johnson 2004) determined the potential net benefits of using glass in basecourse for Ramsay County with a population of 500,000 producing 15,000 tonnes of waste glass per year. Currently in the Ramsay County the waste glass is taken to a landfill 130 km out of town. Discounted costs at a 7% discount rate over a 20-year period were determined for the incremental change in highway costs ($1,154,530); and the avoided costs of not disposing the waste material (ie mixed broken glass) in the landfill including transportation costs ($2,210,441). It was found that reusing the mixed, broken glass as a 10% additive to granular base material resulted in a savings over a 20-year period with a discounted present value of $1,055,911 ($2,210,441 minus $1,154,530) for the Ramsay County. Over a 20-year period this would equate to 300,000 tonnes of waste glass being used in basecourse aggregate at a net present worth benefit of $3.52 per tonne of waste glass.

3. Repeated load triaxial (RLT) study

3.1 Introduction

Multi-stage RLT permanent strain tests following the procedure developed by Arnold et al. (2008) were conducted on basecourse aggregates mixed to specified particle size distributions (gradings) and percentages of crushed glass. The RLT apparatus applies repetitive loading on cylindrical materials for a range of specified stress conditions and the output is deformation (shortening of the cylindrical sample) versus number of load cycles (usually 50,000) for a particular set of stress conditions. Multi-stage permanent strain RLT tests are used to obtain deformation curves for a range of stress conditions to develop models for predicting rutting. Figures 3.1 and 3.2 detail the RLT setup and typical output from a multi-stage permanent strain RLT test. Resilient modulus information can also be obtained for pavement design in CIRCLY and finite element models.

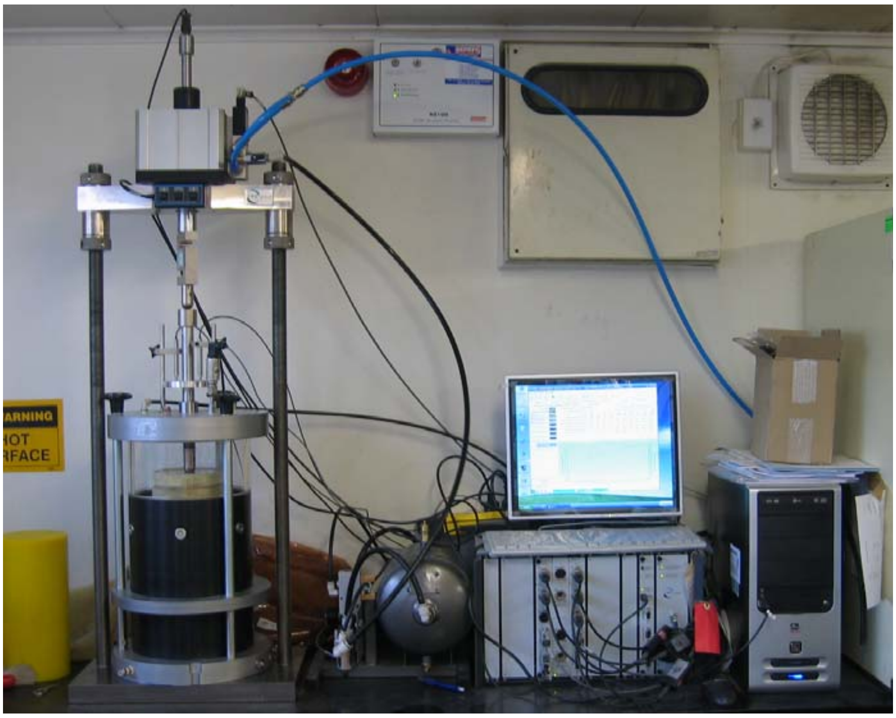

Figure 3.1 RLT apparatus and setup.

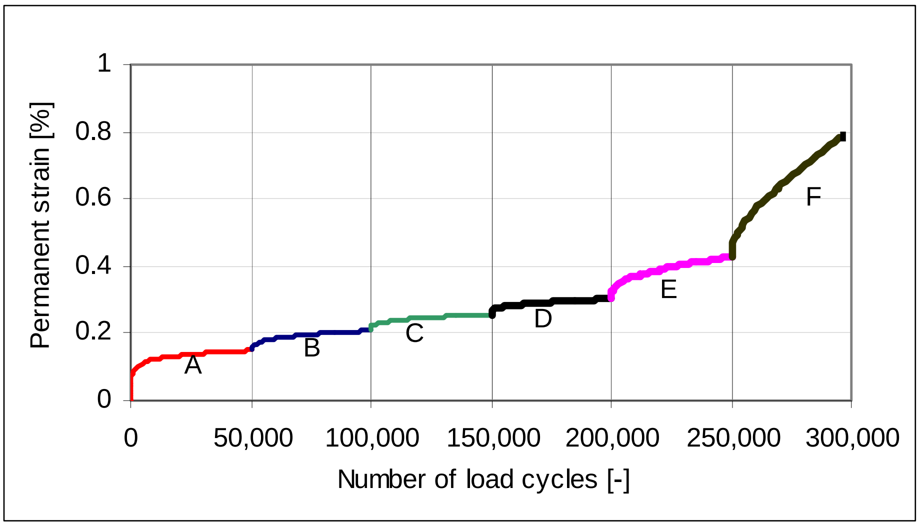

Figure 3.2 Typical output from permanent strain RLT test.

The method developed by Dr Arnold in his doctorate studies at the University of Nottingham (Arnold 2004) was used in this study to interpret the results from RLT testing and predict the rut depth in a pavement. This method has been refined and validated for a range of New Zealand basecourses in the report titled, *Performance tests for road aggregates* (Arnold et al. 2008). The RLT test method is a six-stage test at 50,000 load cycles per stage as detailed in table 3.1.

Table 3.1 RLT testing stresses for six-stage test.

RLT testing stress stage	A	B	C	D	E	F
Deviator stress – q (kPa) (cyclic vertical stress)	90.0	100.0	100.0	180.0	330.0	420.0
Mean stress – p (kPa)	150.0	100.0	75.0	150.0	250.0	250.0
Cell pressure, σ_3 (kPa)	120.0	66.7	41.7	90.0	140.0	110.0
Major principal vertical stress, σ_1 (kPa)	210.0	166.7	141.7	270.0	470.0	530.0
Cyclic vertical loading speed	Haversine at 4 Hz					
Number of loads (*N*)	50,000					
Record and report data electronically in Microsoft Excel	Permanent strain versus load cycles and resilient modulus versus load cycles					

p = mean principle stress (1/3*(σ_1 + 2*σ_3)

q = principle stress difference (σ_1 - σ_3)

To predict the pavement rut depth from RLT tests requires a series of steps. The first step is to develop a mathematical relationship between stress (both vertical and horizontal) with permanent strain rate (slope of each deformation curves ((figure 3.3)), eg % deformation per one million load cycles).

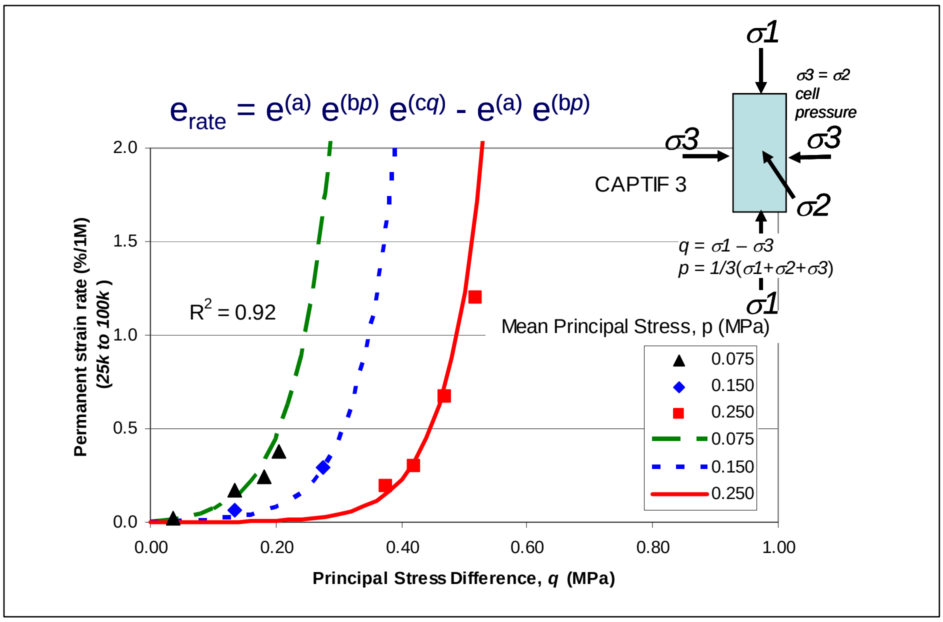

Figure 3.3 Fitting the permanent strain rate model to RLT test results.

The next step is to use a finite element model (to model the non-linear elastic behaviour of a pavement material and to avoid the discontinuities that occur in CIRCLY and result in high tensile stresses) to compute the stresses – both vertical and horizontal underneath a standard axle load (8.2 tonne dual tyred axle or higher if designing for ports etc). Stresses are exported into a spreadsheet to calculate the deformation rate at depth increments in the pavement from the permanent strain model (figure 3.3). Results of Transit NZ's Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) tests showed very good predictions of rutting (Arnold 2004).

Pavement rut depth was predicted for all RLT tests on basecourse aggregates with a range of aggregate basecourse gradings.

3.2 Aggregates and glass quantities tested

The aggregate primarily used in this study was a TNZ M4 AP40 basecourse from Pound Road Quarry in Christchurch. CAPTIF tests commonly use this basecourse due to the quarry's close proximity to the site. Using this basecourse allows the rut depth prediction models to be validated against actual rut depth measured in CAPTIF tests. An added advantage in using the Pound Road basecourse is the number of other RLT tests on this material which supplement the results. The Pound Road aggregate is referred to as Material #1 or CAPTIF 1 as used in other RLT studies.

RLT tests were conducted on mixtures of Material #1 aggregate with 0, 10, 20, 30 and 50% by mass of aggregate of crushed glass. The crushed glass was manufactured by Fulton Hogan in Nelson as part of a trial with the Nelson City Council. Crushed glass ranged in size from pan dust (<0.063 mm) to 9.5 mm. A sieve analysis was undertaken on the crushed glass as shown in table 3.2 along side the current TNZ M/4 requirements (Transit NZ 2006). After the sieve analysis the different glass sizes were separated so that when added to the aggregate the same proportions of glass sizes were achieved for each RLT test. As shown in table 3.2

the as received (and consequently used) percentages of crushed glass do not comply with the current TNZ M/4 requirements. The as received grading was used in this research as it is the grading more likely to be achieved and used in practice.

Table 3.2 Grading of crushed glass as received and used in RLT tests compared with TNZ M/4 *Specification for basecourse aggregate* (Transit NZ 2006) requirements.

Particle size distribution (PSD) from dry sieve analysis		
	Percent passing	
Sieve size	Actual for glass as received	TNZ M/4 (2006) PSD range for glass *(current limits)*
9.5	100	100
6.7	76.1	–
4.75	46.6	70–100
2.36	26.1	35–88
1.18	14.0	15–45
0.30	4.6	4–12
0.075	1.5	0–5

Glass was added directly to the source aggregate (Material #1) which had an original grading in the middle of TNZ M/4 (Transit NZ 2006) with a Talbot exponent *n* value of 0.55. Using the actual grading for the glass detailed in table 3.2 the new resulting grading curves were determined for the glass aggregate mixtures (figure 3.4). As can be seen the grading of the 30% and 50% glass aggregate mixture is outside the limits of TNZ M/4.

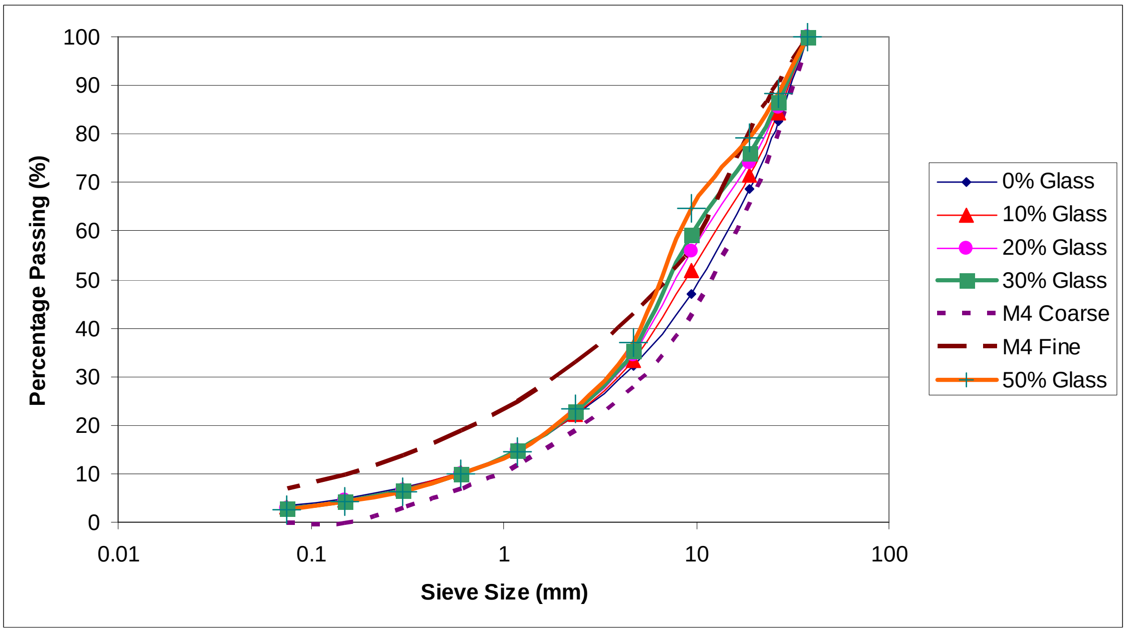

Figure 3.4 Aggregate and glass mixtures grading curves.

3.3 Vibrating hammer compaction tests

The standard specification for compaction of road basecourse is *TNZ B/02 Specification for construction of unbound granular pavement layers* (Transit NZ 2005). Compaction targets are a minimum of 95% of maximum dry density (MDD) and 80% degree of saturation (DOS). MDD and OMC (optimum moisture content to achieve MDD for compaction) are determined by a vibrating hammer compaction test in accordance with NZS 4402 : Test 4.1.3. Targets for RLT testing are 97% MDD and 100% OMC (wet) in drained conditions which is assumed to represent conditions wetter than would be expected to occur. However, tests are less severe than those conducted at saturated and undrained conditions in the RLT apparatus.

Vibrating hammer compaction tests (NZS 4402 : Test 4.1.3) were conducted for the range of aggregate and glass mixtures tested in the RLT apparatus. Results of the compaction tests are shown in table 3.3 and figure 3.5. The maximum density reduces with the addition of glass. There is a slight downwards trend to the OMC as the glass content is increased. The trend should always be a reduction in MDD with increasing glass content (as the specific gravity of glass is less than aggregate). Thus based on the results of the 30% and 0% the MDD values for the other glass percentages were interpolated.

Table 3.3 Vibrating hammer compaction test (NZS 4402 : Test 4.1.3) results.

[1]Material #	[2]Glass %	Maximum dry density (t/m^3)	Optimum moisture content (%)
1	0	2.34	5
1	10	2.23	4.3
1	20	2.30	4.8
1	30	2.26	3.89

[1]Material # 1 is manufactured to a grading in the middle of the TNZ M/4 *Specification for basecourse aggregate.*

[2]Glass is added directly to the aggregate without making adjustments to the original source aggregate grading, hence it is possible that the final grading could be outside specification.

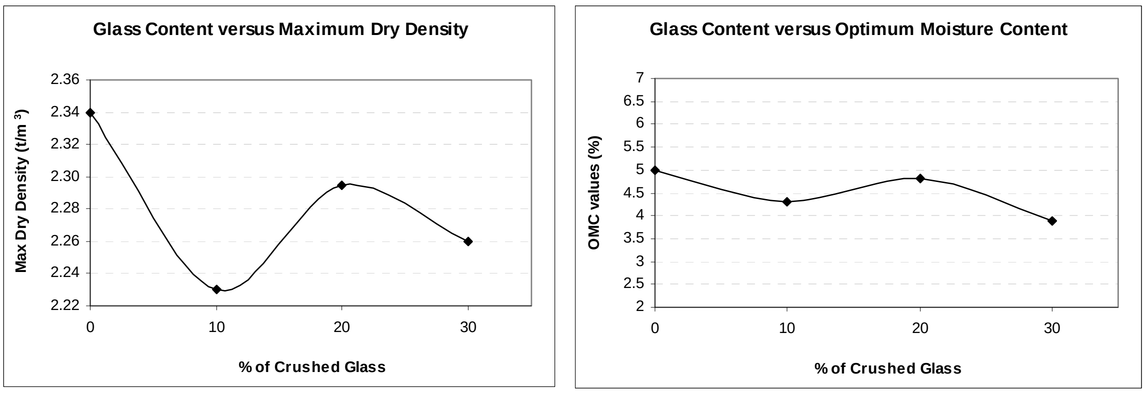

Figure 3.5 Effect of glass content (%) on maximum dry density and optimum moisture content.

3.4 RLT results – University of Canterbury

The first suite of RLT tests was conducted by the University of Canterbury in Christchurch. To confirm the results repeat tests were conducted by Pavespec Ltd at Stevenson Laboratory in Drury. Densities and moisture contents achieved in the university tests are summarised in table 3.4. A test number reference is included to enable reference to the raw results shown in figures 3.6 to 3.11. Interpretation of these results in relation to pavement rut depth prediction is summarised in the next section.

Table 3.4 Summary of RLT tests and identification.

RLT sample		
University of Canterbury test reference #	**Material # and percentage glass**	**Actual moisture content and dry density achieved**
10	Mat #1, 20% glass replacing aggregate (*no change in grading*)	97%MDD, 78%OMC
9	Mat #1, 10% glass replacing aggregate (*no change in grading*)	97%MDD, 78%OMC
11	Mat #1, 10% glass added	98%MDD, 79%OMC
12	Mat #1, 20% glass added	98%MDD, 82%OMC
16	Mat #1, 30% glass added	97%MDD, 88%OMC
17	Mat #1, no glass added (*original aggregate*)	98%MDD, 71%OMC

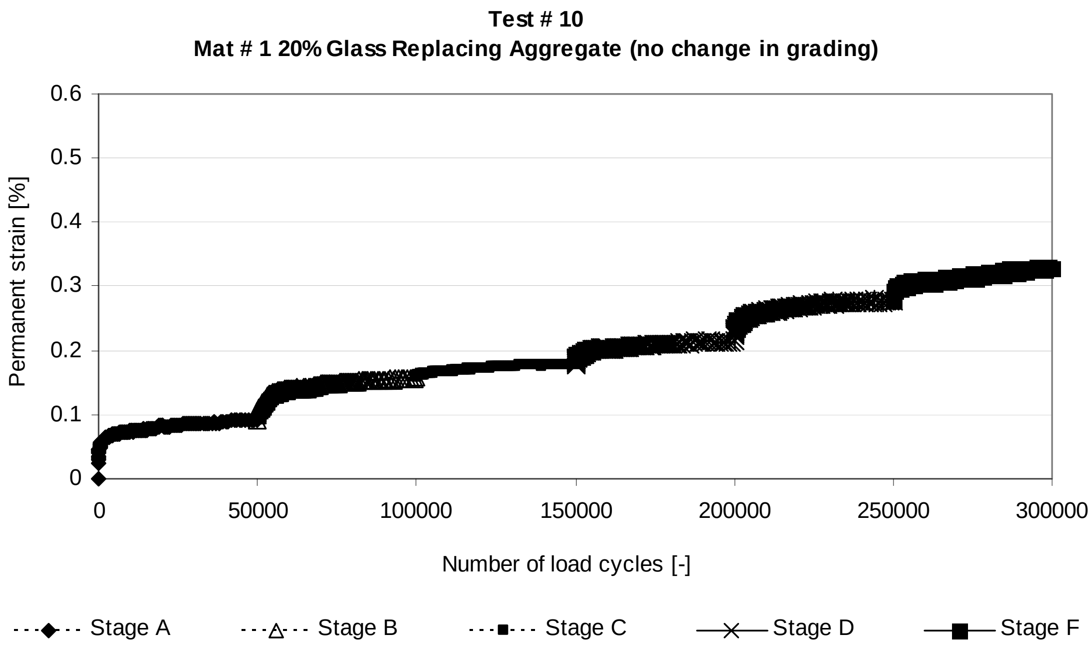

Figure 3.6 RLT result for 20% glass replacing aggregate.

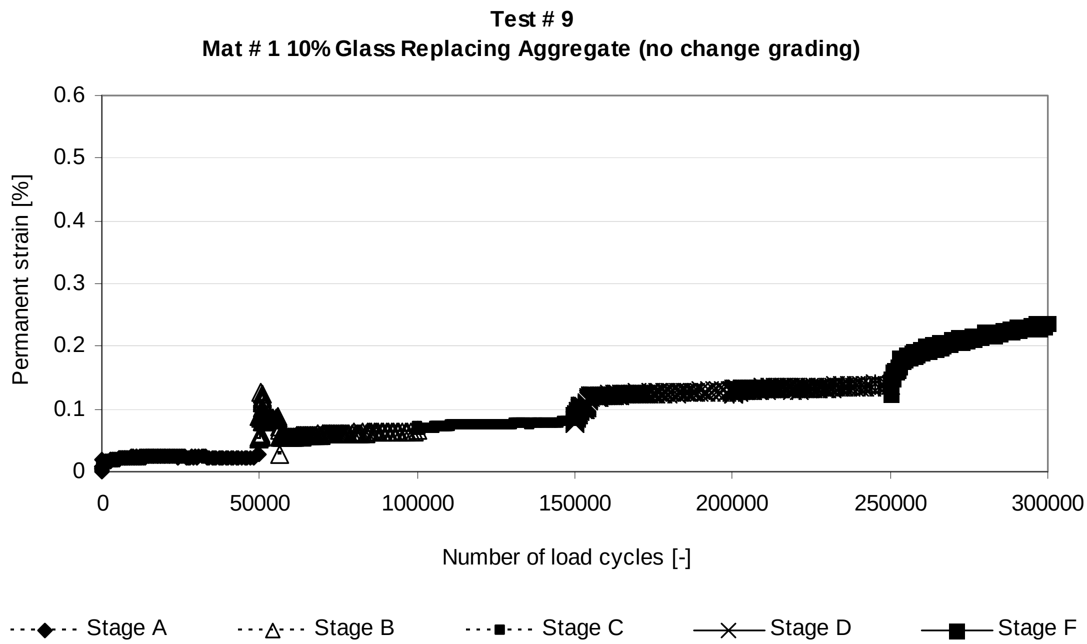

Figure 3.7 RLT results for 10% glass replacing aggregate.

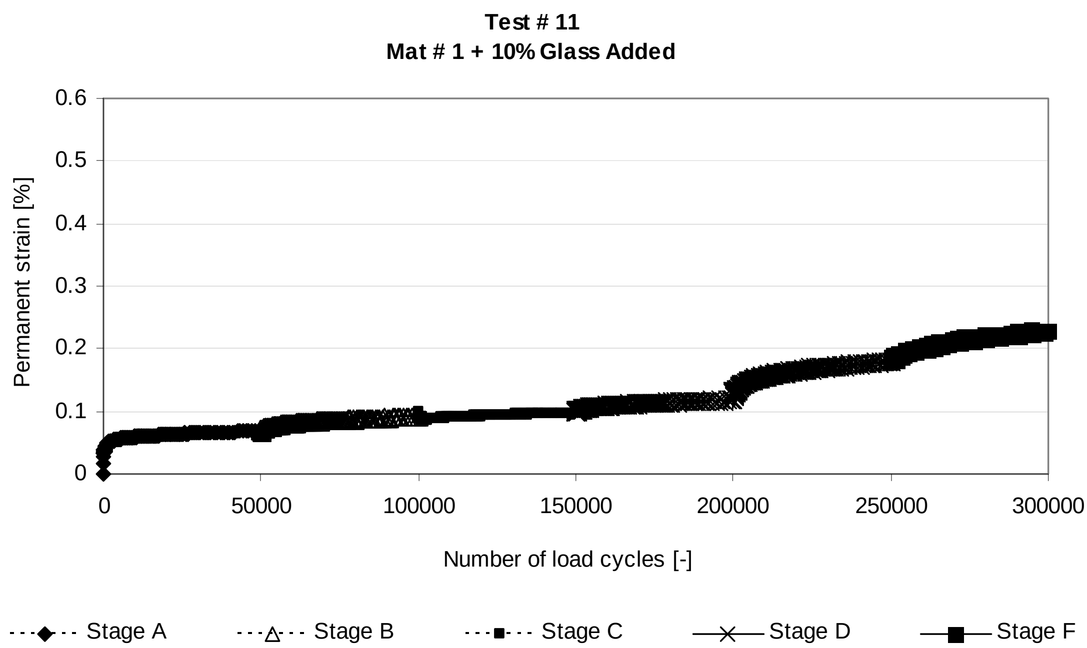

Figure 3.8 RLT results for 10% glass added to aggregate.

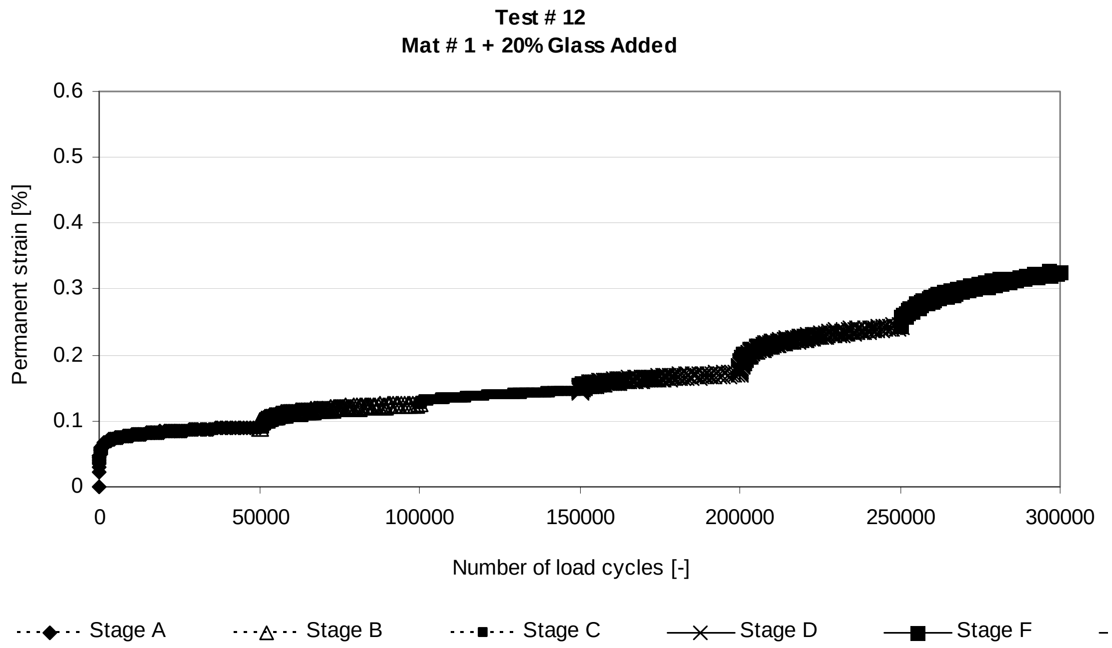

Figure 3.9 RLT results for 20% glass added to aggregate.

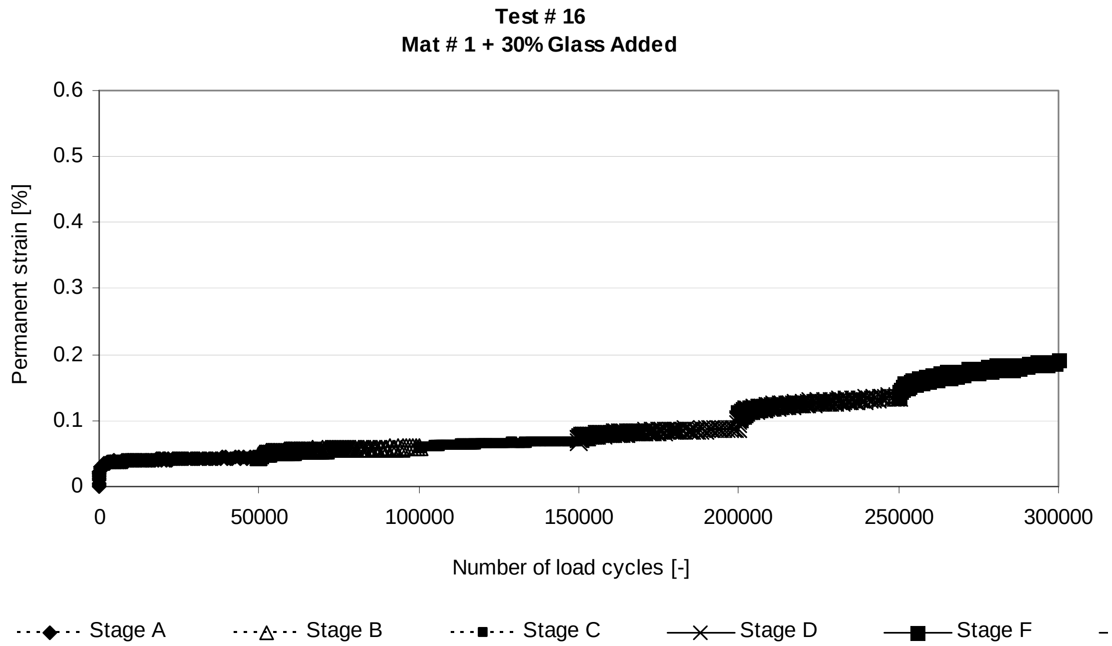

Figure 3.10 RLT results for 30% glass added to aggregate.

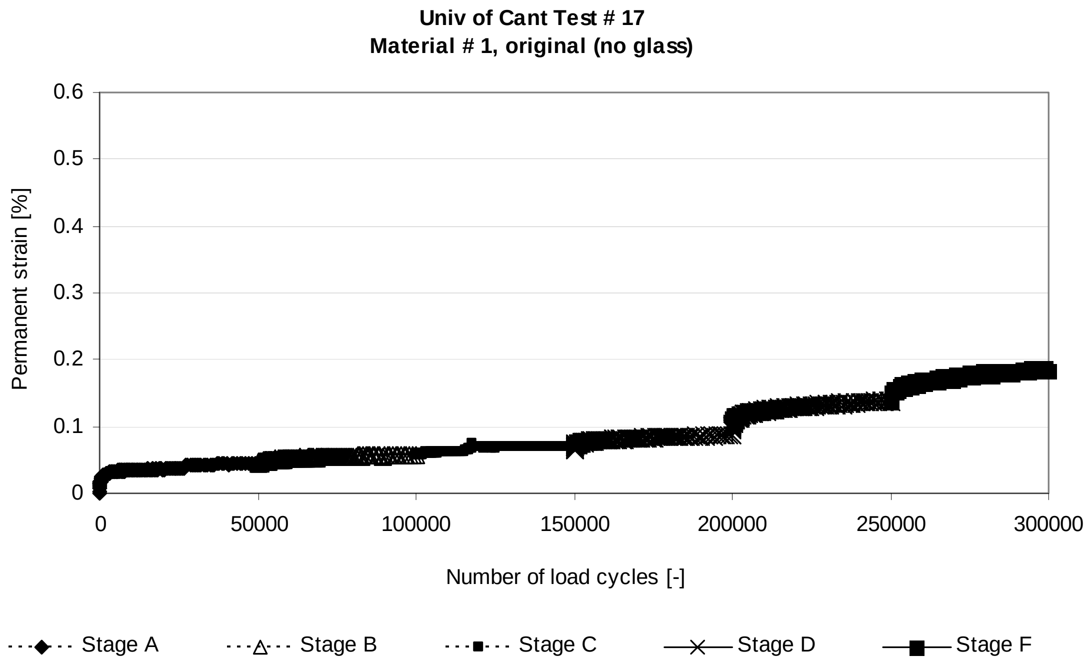

Figure 3.11 RLT results for original source aggregate.

3.5 RLT tests – Pavespec Ltd

Initial tests with glass showed some inconsistencies in results but since then there have been improvements in RLT sample preparation. These have included the re-blending of aggregates and glass to the correct grading and compaction in a frame to ensure even compaction at the targeted density. This reduces any errors from testing to ensure results are repeatable. RLT tests were conducted at the same gradings detailed in table 3.2 at different percentages of glass by mass of aggregate. The raw results of the RLT tests detailed in table 3.5 are shown in figure 3.12. As can be seen, percentages of glass up to 50% by mass of aggregate do not appear to greatly affect the result when compared with the source aggregate (0% glass).

Table 3.5 RLT tests conducted and details of sample preparation.

Pavespec test #	% of glass by mass of aggregate	% of glass to total mass of RLT sample	[1]Final achieved density and moisture content	[2]MDD	[2]OMC
PS0022 Test # 1 CAPTIF1 – 0% glass	0	0	96.3%MDD (DD=2.253 t/m3) ; 89.2%OMC (MC=4.5%)	2.34	5.0
PS0022 Test # 2 CAPTIF1 – 10% glass	10	9.09	97.6%MDD (DD=2.256 t/m3) ; 64.7%OMC (MC=3.2%)	2.31	5.0
PS0022 Test # 3 CAPTIF1 – 20% glass	20	16.67	96.8%MDD (DD=2.216 t/m3) ; 81%OMC (MC=4.1%)	2.29	5.0
PS0022 Test # 4 CAPTIF1 - 30% glass	30	23.08	96.9%MDD (DD=2.19 t/m3) ; 81%OMC (MC=4.1%)	2.26	5.0
PS0022 Test # 5 CAPTIF1 - 50% glass	50	33.33	97.2%MDD (DD=2.144 t/m3) ; 82.2%OMC (MC=4.1%)	2.21	5.0

Note 1: Density and moisture content targeted at the time of sample compaction was 97% MDD and 100% OMC.

Note 2: MDD was interpolated from values obtained for 0 and 30% glass compaction tests in table 3.2 while OMC (optimum moisture content) was kept at 5.0%.

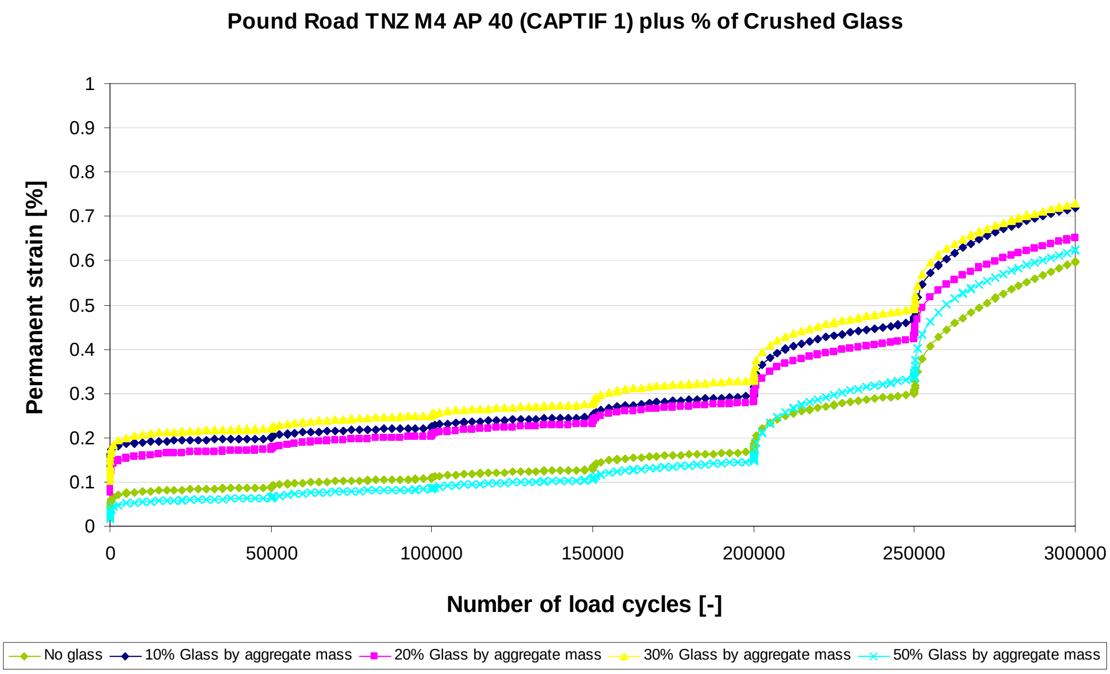

Figure 3.12 Pavespec RLT test results.

3.6 Rut depth predictions

Rut depth from RLT tests was predicted for a typical pavement constructed at CAPTIF (figure 3.13). Rut depths within the subgrade and aggregate were predicted from each RLT result as shown in tables 3.2 and 3.5. Reviewing the results for glass content (figure 3.14 and tables 3.6 and 3.7) does show it has an effect on the strength/ resistance to rutting. However, all the results show good performance as rutting is not expected until after 10 million ESAs. The Pavespec RLT tests show less scatter in the results and confirm that high percentages of glass do not affect the performance of the aggregate.

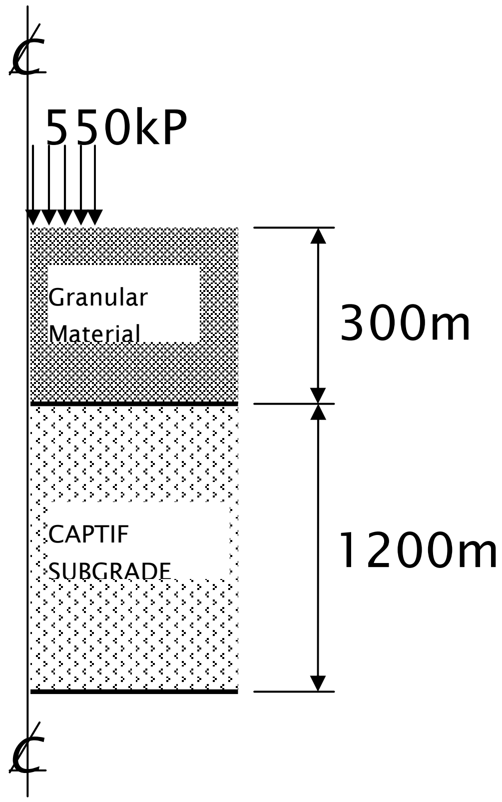

Figure 3.13 CAPTIF pavement cross-section for rut depth prediction.

Table 3.6 Rut depth predictions from University of Canterbury RLT results.

		CAPTIF pavement 300 mm Aggregate over 10 CBR subgrade					
		Total pavement	**Aggregate only**	**Aggregate only**			
		N, ESAs to get 25 mm rut	**N, ESAs to get 10 mm rut in aggregate**	**Long term rate of rutting within aggregate**	**Resilient modulus**	**Average RLT slope**	**Maximum slope**
#	Material # (Table 3.2)	*Million ESAs*	*Million ESAs*	*mm per 1 million ESAs*	*MPa*	*%/1M*	*%/1M*
10	Mat #1, 20% glass replacing aggregate (*no change in grading*)	2.74	5.02	1.8	874	0.289	0.522
9	Mat #1, 10% glass replacing aggregate (*no change in grading*)	3.23	11.68	0.8	786	0.250	0.891
11	Mat #1, 10% glass added	3.30	19.68	0.5	737	0.285	0.512
12	Mat #1, 20% glass added	3.24	15.39	0.6	753	0.392	0.836
16	Mat #1, 30% glass added	3.40	36.54	0.3	665	0.218	0.552
17	Mat #1, no glass added (*original aggregate*)	3.39	26.14	0.4	698	0.207	0.363
	CAPTIF Test 2001, Section 1A, 40kN wheel load	3.8	*Unknown*	*Unknown*			

Table 3.7 Rut depth predictions from Pavespec RLT results.

		CAPTIF pavement 300 mm Aggregate over 10 CBR subgrade					
		Total Pavement	**Aggregate only**	**Aggregate only**			
		N, ESAs to get 25 mm rut	**N, ESAs to get 10 mm rut in aggregate.**	**Long-term rate of rutting within aggregate**	**Resilient modulus**	**Average RLT slope**	**Maximum slope**
#	Material # (Table 9)	*Million ESAs*	*Million ESAs*	*mm per 1 million ESAs*	*MPa*	*%/1M*	*%/1M*
1	PS0022 Test #1 CAPTIF1 – 0% glass	2.88	7.12	1.3	483	0.855	3.2542
2	PS0022 Test #2 CAPTIF1 – 10% glass	3.12	10.47	0.9	517	0.746	2.2174
3	PS0022 Test #3 CAPTIF1 – 20% glass	3.15	11.73	0.8	529	0.736	2.0972
4	PS0022 Test #4 CAPTIF1 – 30% glass	3.19	13.51	0.7	527	0.722	2.009
5	PS0022 Test #5 CAPTIF1 – 50% glass	3.00	9.13	1.0	535	0.814	2.4406

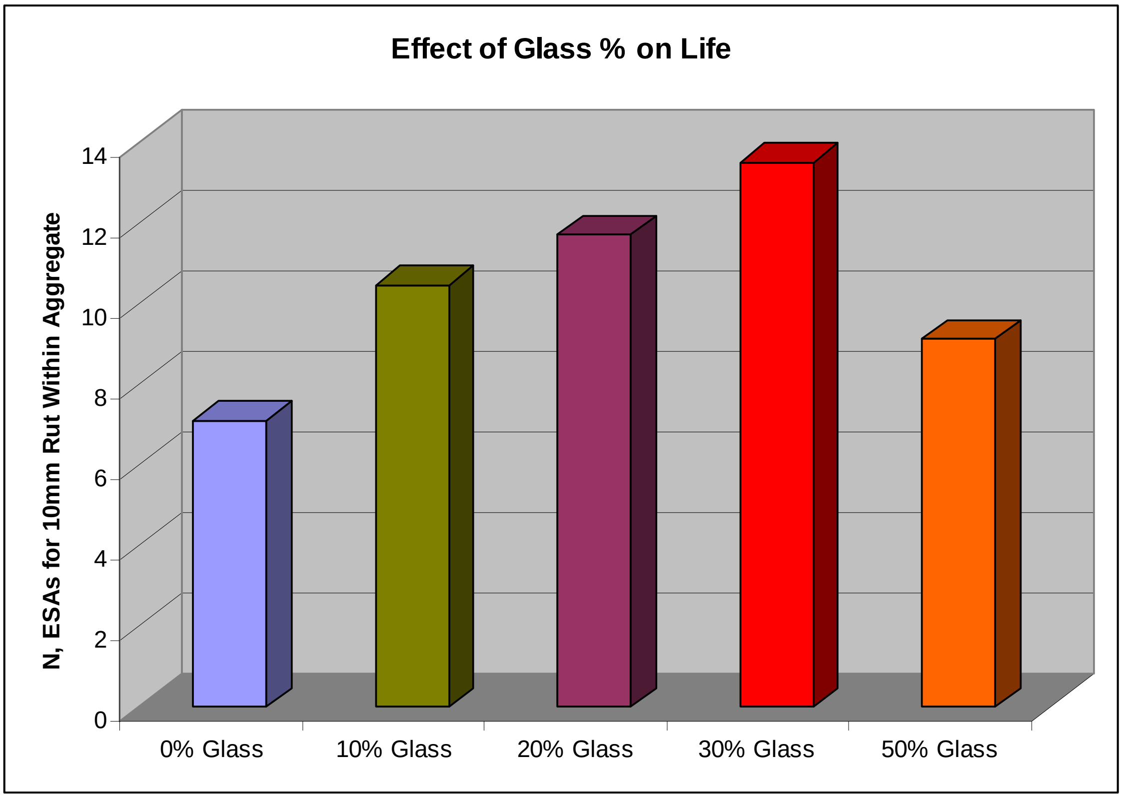

Figure 3.14 Effect of glass content on number of load cycles to achieve a 10 mm rut within aggregate layer for the Pavespec RLT test results.

Due to the power law extrapolation method used to predict rutting, large differences can occur in the rut depth predictions from seemingly similar RLT test results. Therefore, as recommended in the draft RLT specification, any predictions greater than 10 million ESA to rut should be grouped together and classed as a premium aggregate suitable for high trafficked roads. Based on this assumption, glass up to 30% by mass of aggregate can be safely added to a basecourse without affecting its performance. However, this result is only valid for an already high rut resistance aggregate from Pound Road Quarry in Christchurch.

4. Conclusions and recommendations

4.1 Conclusions

Based on the RLT test results it appears that adding crushed glass in quantities of up to 30% by mass has little or no effect on aggregate rut depth performance. This is the case for an already high rut resistance aggregate from Pound Road Quarry in Christchurch. The result is surprising considering 23% of the aggregate is crushed glass less than 9.5 mm in size. Further RLT tests by Pavespec Ltd confirmed this result (at least for use with aggregate from Pound Road Quarry in Christchurch).

4.2 Recommendations

Given that the literature generally shows crushed glass up to 15% by mass is acceptable for basecourse aggregates and the triaxial study showed little effect on aggregate performance, the recommendation is that 15% be used as the new limit for crushed glass in basecourse. Further, the grading envelope for the glass cullet should be expanded to reflect the aggregate used in this study, as typical of what would normally be crushed. Higher percentages may be accepted if proven through RLT testing. Appendix A details the proposed changes to *TNZ M/4 Specification for basecourse aggregate*, table 4: Regional basecourses: Aggregate/reclaimed glass blended basecourse.

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Appendix A Proposed amendment to *TNZ M/4 Specification for basecourse aggregate*: Table 4: Regional basecourses: Aggregate/reclaimed glass blended basecourse.

AGGREGATE / RECLAIMED GLASS BLENDED BASECOURSE

DEFINITION

Overseas experience *and repeated load triaxial tests* suggest that appropriately processed reclaimed glass is well suited for use as a basecourse aggregate. Adding glass to aggregate, in suitable proportions, provides a number of environmental benefits without compromising the mechanical properties of the aggregate.

This extension of the M/4 specification allows up to *15%* reclaimed glass (by mass) to be blended with natural or recycled aggregate for road base construction. The aggregate / reclaimed glass (cullet) blend must comply with the requirements of the M/4 specification except for the variations and additions provided in this table.

Up to *15%* reclaimed glass can also be added to subbase aggregate in accordance with the relevant requirements of the M/4 specification.

Proportions of cullet in excess of *15%* and/or alternative grading envelopes may be used at the discretion of the Transit New Zealand Pavement Engineer, provided that the *traffic loading limit determined from repeated load triaxial testing as per TNZ T/15 (2007) exceeds the design traffic.* ~~Such applications are likely to be restricted to relatively low traffic volume projects and the material may be subject to higher standards with respect to contamination limits.~~

CULLET PROPERTIES

Reclaimed Glass Source	The cullet can originate from a number of glass products, viz: waste food and beverage containers, drinking glasses, window glass, or plain ceramic or china dinnerware. Reclaimed glass from hazardous waste containers, light bulbs, vehicle windscreens, fluorescent tubes or cathode ray tubes shall not be used.
Grading	The cullet shall be crushed to achieve the following gradation: (NZS 4407:1991 Test 3.8.1)

<table>
<tr><td rowspan="2"></td><td colspan="2"><table><tr><td>Sieve
9.5 mm
4.75 mm
2.36 mm
1.18 mm
0.30 mm
0.075 mm</td><td>Percent Passing
100
45 – 100
25 – 88
10 – 45
0 – 12
0 - 5</td></tr></table></td></tr>
<tr><td colspan="2">The plus 4.75 mm component of the cullet must not contain more than 1% of flat or elongated particles, i.e. particles with a maximum to minimum dimension ratio greater than 5:1. The ASTM D 4791 test is appropriate (except that the test sample shall be taken as the material retained on the 4.75 mm sieve).</td></tr>
<tr><td>Contamination Limit</td><td colspan="2">Debris, such as paper, foil, plastic, metal, cork, food residue, organic matter, etc can have a significant influence on the performance of the aggregate / glass material.

The cullet shall not contain more than 5% debris, as determined using the procedure described in RTA Test Method T267 (where “reclaimed glass” is substituted for “recycled concrete”).</td></tr>
<tr><td>Cleanliness</td><td colspan="2">The cullet shall be washed to ensure that undesirable odours are eliminated.</td></tr>
<tr><td colspan="3">PRODUCTION</td></tr>
<tr><td colspan="3">Concentrations of reclaimed glass within the aggregate could have a detrimental influence on the performance of the material in a basecourse layer. Therefore, the aggregate and reclaimed glass shall be mixed thoroughly to ensure that there is an even distribution of glass throughout the basecourse stockpile.</td></tr>
<tr><td colspan="3">CULLET QUALITY ASSURANCE TEST FREQUENCY</td></tr>
<tr><td colspan="3">Tests for compliance with grading, particle shape and contamination shall be carried out at a frequency of two tests (each) per cullet stockpile.</td></tr>
<tr><td>ADDITIONAL PRODUCTION TESTING</td><td colspan="2">As per TNZ M4</td></tr>
<tr><td>TRAFFIC LOADING LIMIT</td><td colspan="2">As per TNZ T/15 assessed by repeated load triaxial testing.</td></tr>
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