Laboratory testing of reclaimed demolition materials for footpaths and shared paths

SWINBURNE UNIVERSITY OF TECHNOLOGY

Final report

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Version 1

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1 PROJECT BACKGROUND

This project is a collaboration between the Swinburne University of Technology and local state government councils.

Demolition waste materials arise from demolition activities. Currently in Victoria, 1.4 million tonnes of crushed brick and 200,000 tonnes of crushed glass are stockpiled annually and these stockpiles are growing. Swinburne University has been actively undertaking research in the use of various recycled demolition materials as pavement sub-base and in other geotechnical applications. A recently completed research project by Swinburne University with demolition materials enabled VicRoads to allow new and rehabilitated roads to be made up of up to 15 per cent crushed brick (a significant increase on the current standards that only allows 3 per cent).

Traditional footpath and bicycle path building materials are becoming scarce in some regions. In some cases, the use of these materials is unsustainable from both an environmental and cost perspective. This has led to this proposed project to investigate the usage of recycled crushed glass, crushed brick and crushed concrete in these applications. The development of a procedure for the evaluation of these reclaimed products in footpaths and bicycle paths as a base, and sub-base material would result in an increased level of confidence within local government councils as to their likely in-service performance and appropriate application.

This applied research project is significant as it will assess the geotechnical engineering properties and performance of reclaimed materials in footpaths and shared paths, reduce the demand for virgin materials and reduce the quantity of material deposited in landfill. This project will investigate the usage of recycled crushed brick and crushed glass in blends with crushed rock and crushed concrete in footpath base and subbase applications. Laboratory testing was carried out at Swinburne.

This research project was undertaken in the three phases detailed below:

Phase 1: Project plan and sampling of recycled materials

Phase 2: Geotechnical laboratory testing of reclaimed materials

Phase 3: Submission of a report at the completion of the laboratory testing.

The project outcomes include:

- Assist local government councils in the development of an accepted process for the evaluation of reclaimed materials in footpaths and bicycle paths.
- Provide improved knowledge in order to support the development and lead to improvements to the material specifications, construction standards and the geotechnical design of footpaths and bicycle paths based on the research results.
- Develop long-term strategic research alliances between academic institutions (SUT) and local Victorian government councils in order to apply advanced knowledge and technologies to the usage of reclaimed Construction and Demolition materials.

Personnel

A key feature of this project was the collaboration of the chief investigators who as a team have extensive research and consulting experience in the field of geotechnical engineering, reclaimed and waste materials, laboratory testing, field testing, field instrumentation, in-situ testing, numerical analysis and civil engineering.

Dr Arul Arulrajah (Swinburne University of Technology) has over 18 years experience as a professional civil engineer in industry in the Asia-Pacific region and has been in academia since 2006. He has expertise in geotechnical engineering, laboratory characterisation, site investigation, in-situ testing, field instrumentation, geotechnical design and civil project management.

Dr Binh Vuong (Swinburne University of Technology) has over 30 years experience as a professional civil engineer with 5 years in geotechnical engineering and 26 years in pavement engineering at ARRB Group. He has expertise in pavement design, laboratory characterisation methods, field performance testing, construction and material specifications and numerical modelling.

Prof John Wilson (Swinburne University of Technology) has over 25 years experience as a professional civil engineer with 10 years in industry and 15 years as an academic at University of Melbourne and Swinburne University of Technology. He has expertise in infrastructure systems and has had wide experience leading and contributing to multi-disciplinary collaborative research and consulting projects.

Thurairatnam Aatheesan (Swinburne University of Technology) is currently undertaking his PhD in Geotechnical Engineering. He is working on recycled materials such as crushed brick, crushed concrete and crushed rock.

M. M. Younus Ali (Swinburne University of Technology) is currently undertaking his PhD in Geotechnical Engineering. He is working on recycled materials such as crushed glass, crushed concrete, crushed rock and road asphalt pavement (RAP). He has more than 7 years experience in teaching and research works in Civil Engineering. Other than teaching, he was also involved in design & consultancy work of Building and Foundation Engineering, Supervision and Monitoring of construction work, Sub-soil investigation of different places of Bangladesh & testing of Civil Engineering construction and concrete materials.

2 RECYCLED MATERIAL SOURCES

Samples of crushed brick, crushed glass, crushed concrete (class 3) and crushed rock (manufactured from recycled basalt excavation rock) for this project was mostly obtained from Alex Fraser Recycling site at Laverton North. Some crushed brick, crushed rock and crushed concrete samples were also obtained from Delta Recycling site at Sunshine.

Crushed brick from the Alex Fraser Recycling site typically comprises approximately 70% brick and 30% other materials such as asphalt, concrete and rock. The samples collected comprised graded aggregates up to 20 mm in size. Crushed glass of particle size less than 5 mm for this research project was also obtained from Alex Fraser Recycling site at Laverton. Figures 1 to 4 present the various recycled aggregate stockpiles at Alex Fraser Recycling, Laverton.

The crushed rock sourced originates from "basalt floaters" or surface excavation rock (basalt) which commonly occurs near the surface to the west and north of Melbourne. Traditionally this material would have been discarded as waste (often into landfill), however, because this rock is generally hard and durable VicRoads has allowed (under controlled conditions) its use for pavement subbase and other uses. The rock is often encountered in subdivisional excavation and drainage lines as well as other subsurface infrastructure.

Figure 1: Crushed brick (20 mm) stock pile - Alex Fraser Recycling, Laverton

Figure 2: Crushed glass (5 mm and smaller) stock pile - Alex Fraser Recycling, Laverton

Figure 3: Crushed concrete (20 mm) stockpile - Alex Fraser Recycling, Laverton

Figure 4: Crushed rock (20 mm) stockpile - Alex Fraser Recycling, Laverton

3 LABORATORY TESTING METHODOLOGY

This section describes the test methods that were used to determine the engineering properties of crushed glass and crushed brick when blended with various proportions of crushed concrete (Class 3) and crushed rock (Class 3). The laboratory testing program will comprise of the following tests:

- Particle Size Distribution
- Particle Density
- Water Absorption
- Modified Compaction
- Modified California Bearing Ratio (CBR)
- pH
- Clay Content
- Plasticity Index
- Organic Content
- Los Angeles Abrasion Loss
- Flakiness Index
- Permeability

Particle Size Distribution

Particle size distribution tests were performed in accordance with AS 1141.11 "Particle size distribution by sieving" (AS 1141.11, 1996). The Australian Standard sieves with the aperture sizes of 19 mm, 13.2 mm, 9.5 mm, 6.7 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 425 µm, 300 µm, 150 µm and 75 µm will be used. The minimum amount of 3 kilograms will be sieved and the particle size distribution will be plotted for each blend.

Particle Density

Particle density tests for coarse material retained on 4.75 mm sieve were performed in accordance with AS 1141.6.1 "Particle density and water absorption of coarse aggregate–Weighing-in-Water Method". Particle density tests for fine material passing 4.75 mm sieve will be undertaken in accordance with AS 1141.5 "Particle density and water absorption of fine aggregate".

Water Absorption

Water absorption tests for coarse aggregates were undertaken in accordance with AS 1141.6.1 "Particle density and water absorption of coarse aggregate–Weighing-in-Water Method". Water absorption tests for fine aggregates were performed in accordance with AS 1141.5 "Particle density and water absorption of fine aggregate".

Modified Compaction

Modified compaction tests were undertaken in accordance with AS 1289.5.2.1 "Soil compaction and density tests – Determination of the dry density/moisture content relation of a soil using modified compactive effort" to determine the maximum dry density and optimum moisture content. Samples will be prepared in a 105 mm diameter mould, having a capacity of 1000 cm^3 from coarse and fine aggregates smaller than 19 mm (i.e. passing the 19 mm sieve).

Modified California Bearing Ratio (CBR)

California Bearing Ratio tests were undertaken in accordance with AS 1289.6.1.1 "Soil strength and consolidation tests – Determination of the California Bearing Ratio of a soil – Standard laboratory method for a remoulded specimen". The samples will be prepared at their optimum moisture content using modified compactive effort (98% to 100% Maximum Dry Density) and tested under four days soaked condition. As each prepared sample will be 19 mm minus, there will be no need to remove any oversize and the full sample can be tested.

pH

pH tests were performed in accordance with AS 1289.4.3.1 "Soil chemical tests - Determination of the pH value of a soil - Electrometric method". All samples will consist of material passing 2.36 mm sieve.

Clay Content

Hydrometer tests were undertaken to determine the clay content of samples in accordance with ASTM D 422-63 "Standard Test Method for Particle-Size Analysis of Soils".

Plasticity Index

Plastic limit, liquid limit and plasticity index tests were undertaken in accordance with AS 1289.3.1.1 "Soil classification tests – Determination of the liquid limit of a soil – Four point Casagrande method" for liquid limit and AS 1289.3.2.1 "Soil classification tests – Determination of the plastic limit of a soil – Standard method" for plastic limit.

Organic Content

Organic content tests were undertaken in accordance with ASTM D 2974-00 "Standard Test Methods for Moisture, Ash and Organic Matter of Peat and Other Organic Soils".

Los Angeles Abrasion Loss

Los Angeles Abrasion Loss tests were undertaken in accordance with AS 1141.23 "Methods for sampling and testing aggregates – Los Angeles Value".

Permeability

Permeability tests were undertaken in accordance with AS 1289.6.7.2 "Soil strength and consolidation tests – Determination of permeability of a soil – Falling head method for a remoulded specimen".

Recycled Crushed Brick and Crushed Glass Blends

Recycled glass and crushed brick were blended with various percentages of crushed rock and recycled crushed concrete for the various tests. The blend mixtures were prepared by hand mixing to the required percentages by weight. The details of the recycled glass and crushed brick blends for each of the tests are presented in Tables 1 and 2.

Table 1: Crushed Brick Blends

Sample description	Blending percentage		
	Crushed Rock (CR) Class 3	Recycled Crushed Concrete (RCC) Class 3	Crushed Brick (CB)
CB10/CR90	90		10
CB15/CR85	85		15
CB20/CR80	80		20
CB30/CR70	70		30
CB40/CR60	60		40
CB50/CR50	50		50
CB10/RCC90		90	10
CB15/RCC85		85	15
CB20/RCC80		80	20
CB30/RCC70		70	30
CB40/RCC60		60	40
CB50/RCC50		50	50

Table 2: Crushed Glass Blends

Sample description	Blending percentage		
	Crushed Rock (CR) Class 3	Recycled Crushed Concrete (RCC) Class 3	Recycled Glass (RG)
RG10/CR90	90		10
RG15/CR85	85		15
RG20/CR80	80		20
RG30/CR70	70		30
RG40/CR60	60		40
RG50/CR50	50		50
RG10/RCC90		90	10
RG15/RCC85		85	15
RG20/RCC80		80	20
RG30/RCC70		70	30
RG40/RCC60		60	40
RG50/RCC50		50	50

4 RECYCLED CRUSHED BRICK

4.1 CRUSHED BRICK BLENDED WITH CRUSHED CONCRETE

Laboratory tests were performed on prepared samples of crushed brick blended with crushed concrete (Class 3) obtained from the Alex Fraser Recycling site at Laverton as well as from the Delta Recycling site at Sunshine. The particle size distribution results prior to compaction and after compaction for crushed brick blended with crushed concrete (Class 3) sourced from the Alex Fraser Recycling, Laverton site is summarised in Table 3 and Table 4. Table 5 summarises the engineering properties of crushed brick blended with crushed concrete (Class 3) sourced from Alex Fraser Recycling, Laverton. Engineering properties of crushed brick blended with crushed concrete (Class 3) sourced from Delta Recycling, Sunshine is summarised in Table 6. The differences in CBR results for the Series 1 and Series 2 tests could be due to slight differences in the aggregate strengths and proportions. The Series1 tests and Series 2 tests were carried out on different bulk samples as they were carried out several months apart.

Table 3: Particle size distribution (before compaction)

Sample Description	CB50/ RCC50	CB40/ RCC60	CB30/ RCC70	CB25/RCC75		CB20/RCC80		CB15/RCC85		CB10/RCC90		RCC100	
Brick Content (%) by weight	50	40	30	25		20		15		10		0	
Particle size (mm)	Percentage of total passing (%)												
	Ser 1	Ser 1	Ser 1	Ser 1	Ser 2	Ser 1	Ser 2	Ser 1	Ser 2	Ser 1	Ser 2	Ser 1	Ser 2
26.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	99.1	98.5	99.3	99.3	99.4	99.4	98.9	98.7	99.6	99.7	99.5	99.1	98.8
13.2	87.3	88.3	88.1	89.6	88.8	88.8	88.9	82.3	88.3	83.5	89.5	79.0	86.7
9.5	76.6	75.1	74.7	80.1	75.7	78.9	77.6	70.3	75.4	72.8	77.1	67.6	74.8
4.75	58.4	56.0	54.3	62.9	56.0	56.5	57.1	50.9	55.4	51.1	57.2	49.3	55.4
2.36	45.0	45.9	42.4	49.5	43.4	44.9	44.4	39.0	42.8	39.0	44.4	38.3	43.3
0.075	7.5	5.7	5.8	8.0	6.6	4.8	6.4	4.7	6.1	4.5	6.7	3.6	5.8

Table 4 : Particle size distribution (after compaction)

Sample Description	CB50/ RCC50	CB40/ RCC60	CB30/ RCC70	CB25/ RCC75	CB20/ RCC80	CB15/ RCC85	CB10/ RCC90	RCC100
Brick Content (%) by weight	50	40	30	25	20	15	10	0
Particle size (mm)	Percentage of total passing (%)							
26.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	99.1	98.1	99.4	100.0	99.2	99.5	99.4	98.7
13.2	88.2	87.1	85.6	85.8	87.6	83.0	88.8	82.2
9.5	76.9	76.2	74.8	77.3	78.0	70.9	81.6	73.5
4.75	57.6	56.8	56.2	58.8	59.7	47.8	67.6	55.6
2.36	45.2	43.9	45.5	47.2	48.2	36.3	55.9	44.6
0.425	24.9	22.2	25.4	25.7	24.1	16.9	28.3	22.6
0.075	8.3	7.7	9.7	9.5	7.3	4.8	8.1	6.9

The after compaction gradings show that some breakdown is occurring under compaction, however compliance with normal after compaction requirements is still achieved. It would be interesting to see what level breakdown occurs under a field compaction conditions and field trails are suggested to gauge the potential impacts.

Table 5: Engineering properties of crushed brick blended with crushed concrete (Class 3) - Alex Fraser Recycling, Laverton site

Sample Description		CB50/ RCC50	CB40/ RCC60	CB30/ RCC70	CB25/ RCC75	CB20/ RCC80	CB15/ RCC85	CB10/ RCC90	RCC100
Brick Content (%) by weight		50	40	30	25	20	15	10	0
Test description		Test results							
Particle density (Coarse)- Series 1(t/m^3)		2.69	2.68	2.67	3.08	2.68	2.71	2.47	2.76
Particle density (Coarse)- Series 2(t/m^3)					2.71	2.71	2.71		
Particle density (Fine) (t/m^3)					2.43	2.60	2.41		
Water absorption (Coarse) (%)- Series 1		5.36	5.91	5.56	5.23	4.95	5.36	5.69	4.66
Water absorption (Coarse) (%)- Series 2					5.4	5.7	5.5		
Water absorption (Fine) (%)					6.9	7.5	8.7		
CBR (%)	Series1	103	134	117	88	104	169	97	160
	Series2	111		190	141	152	132	177	118
Los Angeles abrasion		33	32	30	28	30	31	32	
Permeability (m/s)		1.1×10^{-8}		1.5×10^{-8}	2×10^{-8}	2×10^{-8}	2×10^{-8}		
Organic content (%)		2.15	2.35	2.29	2.23	2.36	2.44	2.14	2.25
pH		10.64	10.96	11.11	11.44	11.30	10.88	11.05	11.49
Compaction (Modified)	Max dry density (t/m^3)	1.99	1.99	1.95	1.94	1.95	1.99	1.95	1.96
	Opt moisture content (%)	11.00	11.50	12.50	12.00	11.70	11.70	12.00	12.00
Atterberg Limit	Plastic limit	N.O	N.O	N.O	N.O	N.O	N.O	N.O	N.O
	Liquid limit	N.O	N.O	N.O	N.O	N.O	N.O	N.O	N.O
	Plasticity Index	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P
Fine content (%)		7.5	5.7	5.8	8.0	4.7	4.8	4.5	3.6
Flakiness Index		14	13	13	13	11	12	11	11

Table 6: Engineering properties of crushed brick blended with crushed concrete (Class 3) - Delta Recycling, Sunshine site

Sample Description		CB30/RCC70	CB25/RCC75
Brick content (%) by weight		30	25
Test description		Test results	
Particle density (Coarse) (t/m^3)		2.69	2.73
Water absorption (Coarse) (%)		4.84	5.44
CBR (%)		102	113
Max dry density (t/m^3)		1.95	1.95
Optimum moisture content (%)		12.5	12.5
Particle density	Sieve size	Total passing (%)	
	26.5mm	100.0	100.0
	19.0mm	99.7	99.8
	13.2mm	88.3	83.4
	9.50mm	68.4	66.7
	4.75mm	45.5	47.8
	2.36mm	34.5	37.1
	0.425mm	15.8	17.1
	0.075mm	4.0	4.1

4.1.1 Particle Size Distribution

The grading limits of all blends before and after compaction were found to be within the VicRoads specified lower and upper bound as presented in Figure 5, Figure 6 and Figure 7.

❖ **Before compaction**

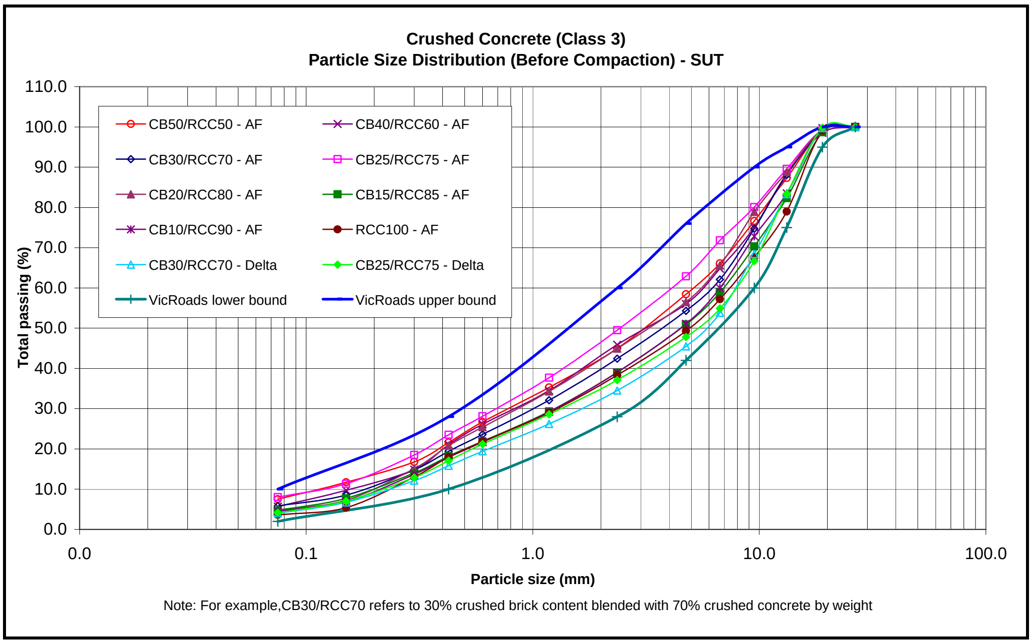

Figure 5: Particle size distribution (before compaction) for crushed brick blended with crushed concrete (Class 3) - Series 1

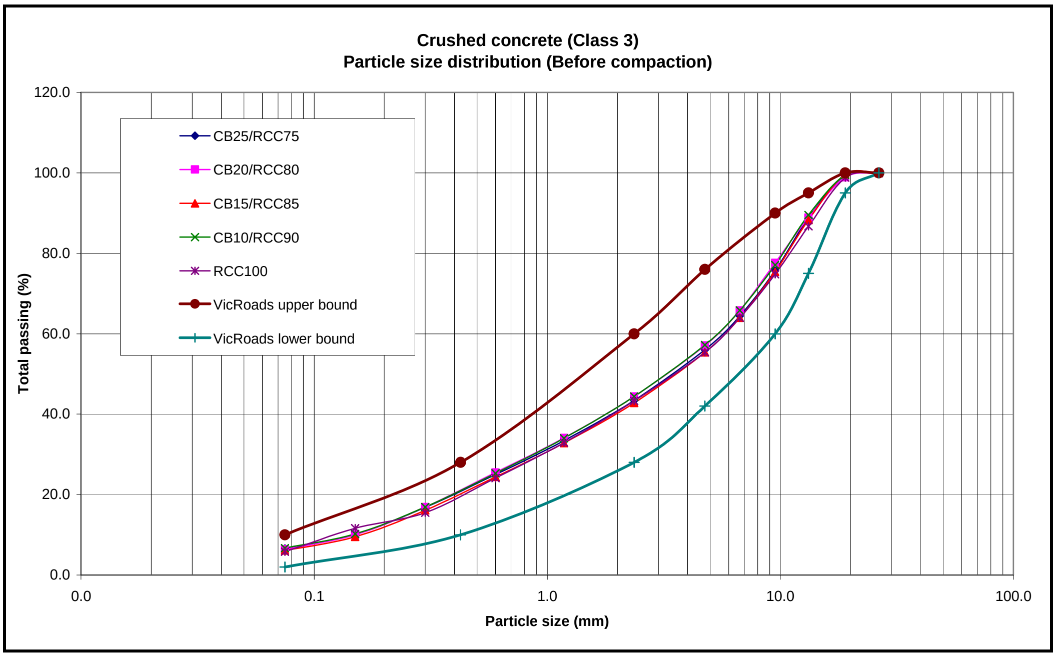

Figure 6: Particle size distribution (before compaction) for crushed brick blended with crushed concrete (Class 3) – Series 2

❖ After compaction

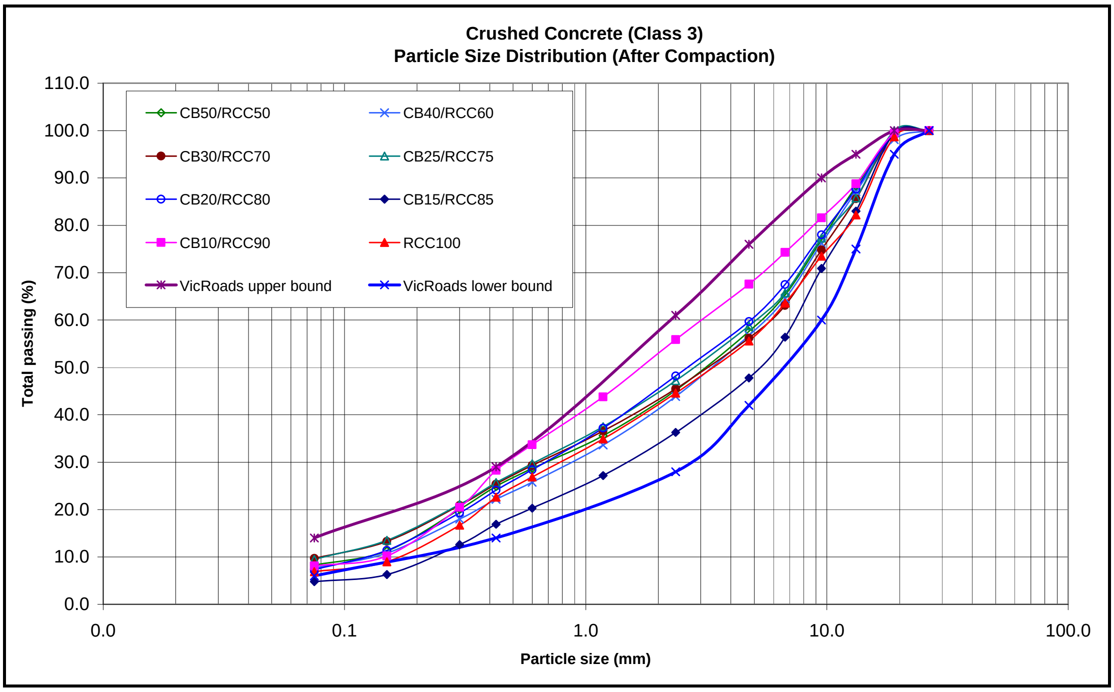

Figure 7: Particle size distribution (after compaction) for crushed brick blended with crushed concrete (Class 3)

The before and after compaction gradings of the random samples indicate that the materials appear to be remaining reasonably well graded through the compaction process and this will generally aid the compaction process.

Of importance is that the results are within the VicRoads specified lower and upper bounds. The difference in the trends of the curves would be due to slight variations in the constitution of the samples.

4.1.2 Particle Density

❖ Coarse material

The particle densities of coarse blended aggregates passing 19 mm and retained on 4.75 mm are in the range between 2.4 to 3.1. Particle density results for all blends are presented in Figure 8. The samples with blends CB25/RCC75 and CB10/RCC90 have some variations to the trends of the other blends, possibly due to some sample variations, but results are within reasonable ranges.

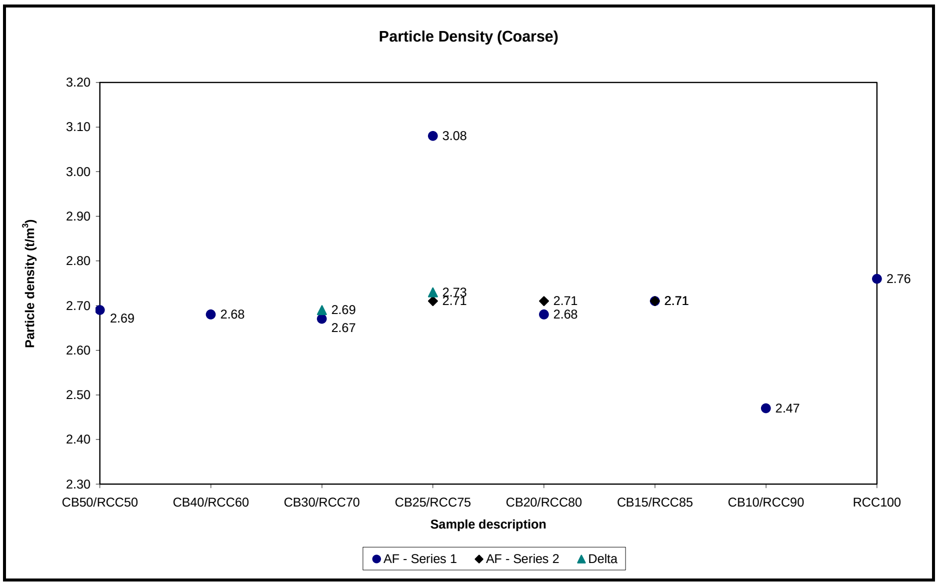

Figure 8: Particle density (coarse) of crushed brick blended with crushed concrete (Class 3)

❖ Fine material

The particle densities of fine blended aggregates passing 4.75 mm range between 2.4 to 2.6. Particle density results for all blends are presented in Figure 9.

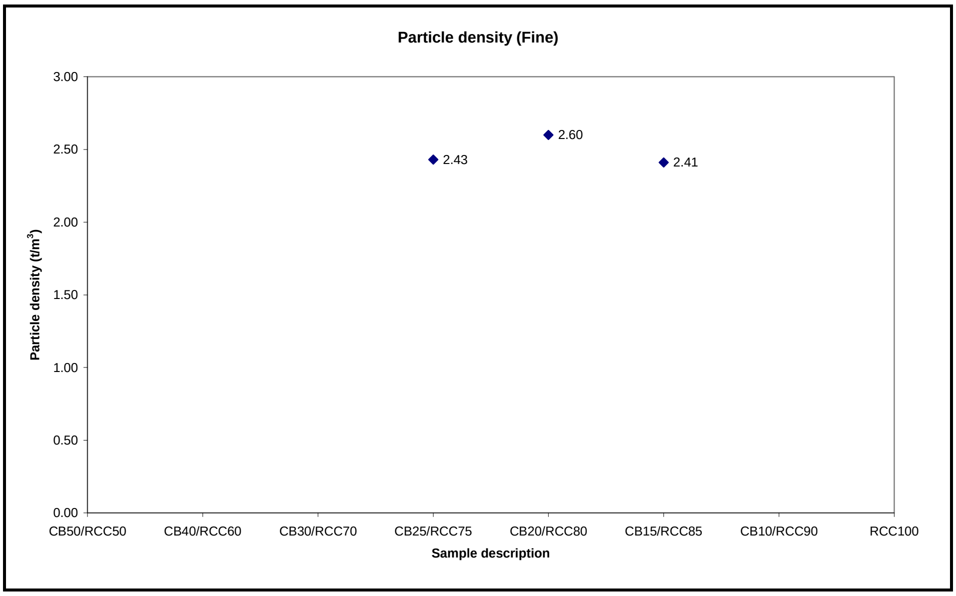

Figure 9: Particle density (fine) of crushed brick blended with crushed concrete (Class 3)

4.1.3 Water Absorption

❖ Coarse material

The water absorptions of coarse blended aggregates passing 19 mm and retained on 4.75 mm range between 4% to 6%. Water absorption results for all blends are presented in Figure 10.

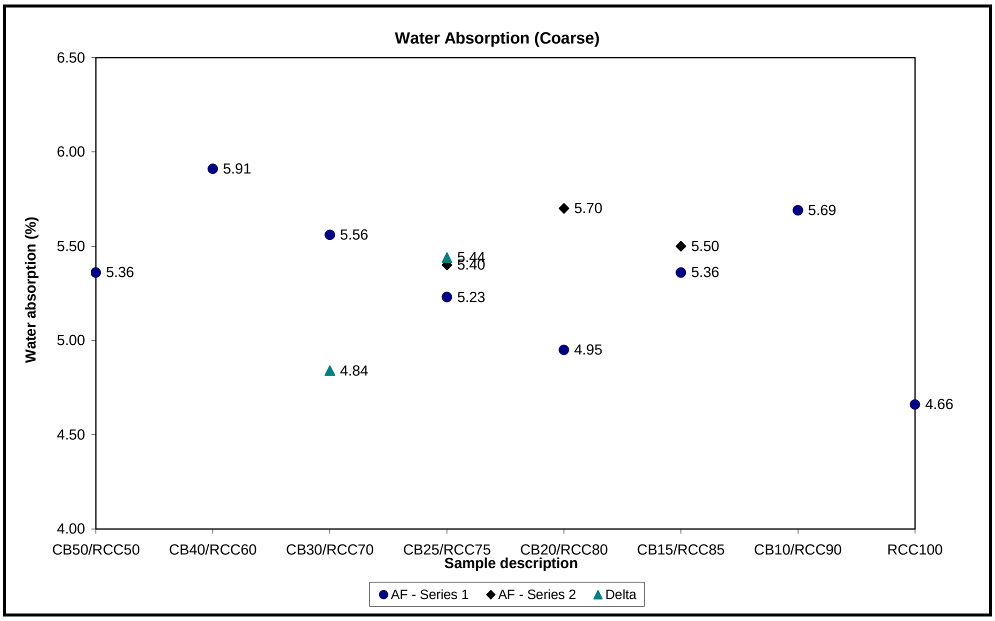

Figure 10: Water absorption (coarse) of crushed brick blended with crushed concrete (Class 3)

❖ Fine material

The water absorptions of fine blended aggregates passing 4.75 mm range between 6% to 9%. Water absorption results for all blends are presented in Figure 11.

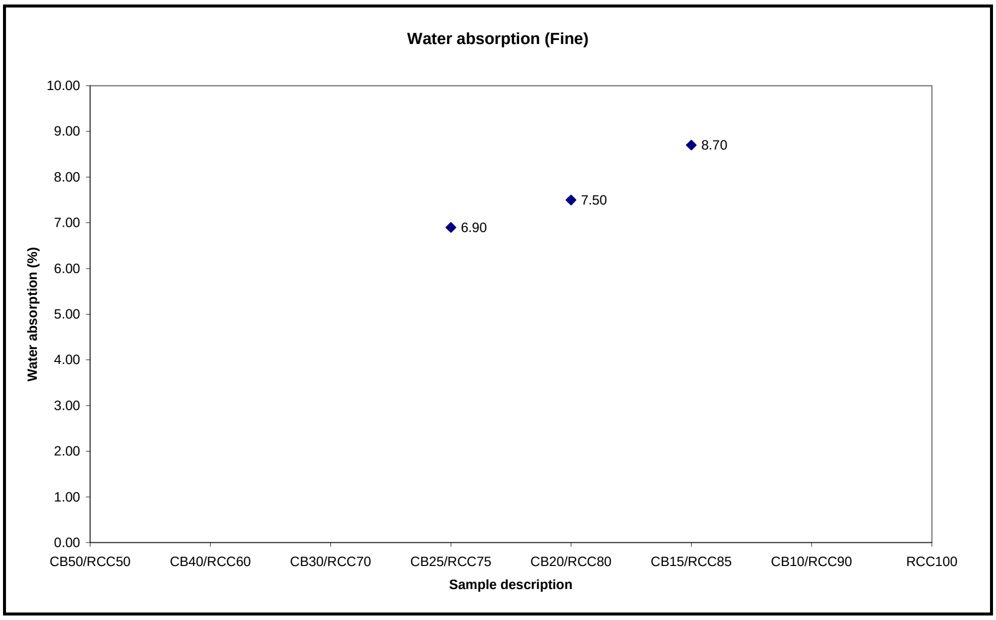

Figure 11: Water absorption (fine) of crushed brick blended with crushed concrete (Class 3).

The higher water absorption for the crushed concrete blends along with the generally higher optimum moisture contents will mean that the crushed concrete blends may be less attractive to contractors given the current difficulties in sourcing of suitable water sources for road construction activities.

4.1.4 Modified Compaction

The maximum dry densities of blends following compaction range between 1.94 to 1.99 as presented in Figure 12. The optimum moisture contents for blends range between 11.0% to 12.5% as shown in Figure 13.

❖ **Maximum dry density**

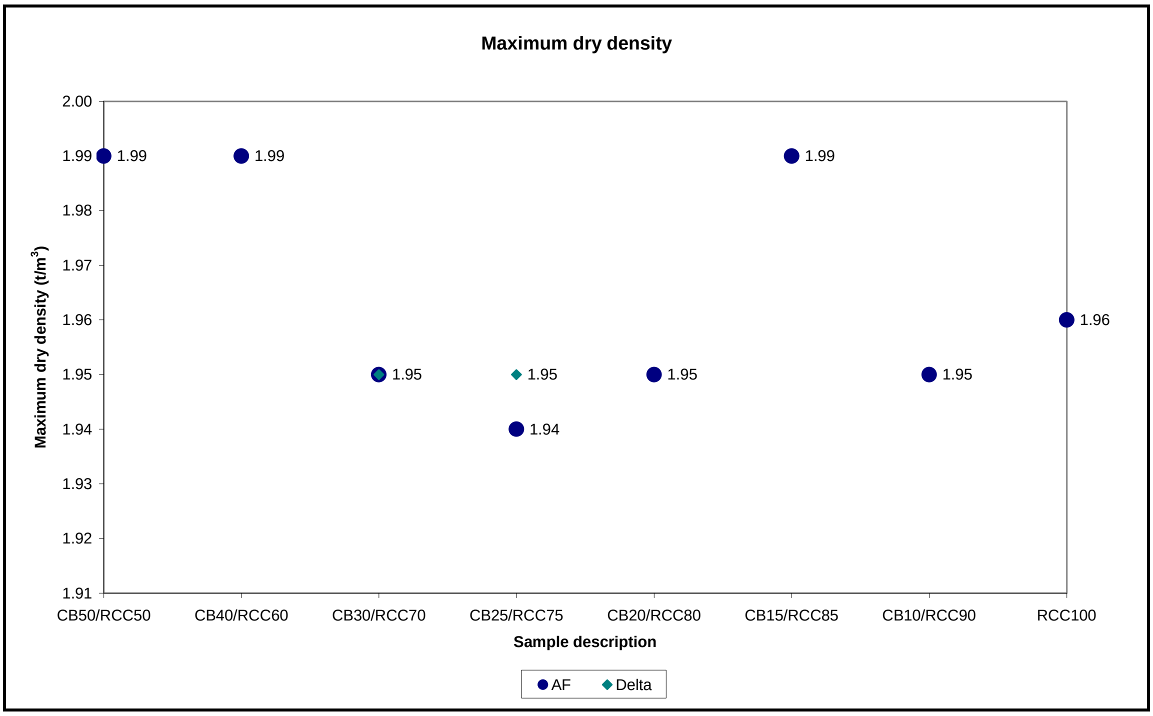

Figure 12: Maximum dry density of crushed brick blended with crushed concrete (Class 3)

❖ **Optimum moisture content**

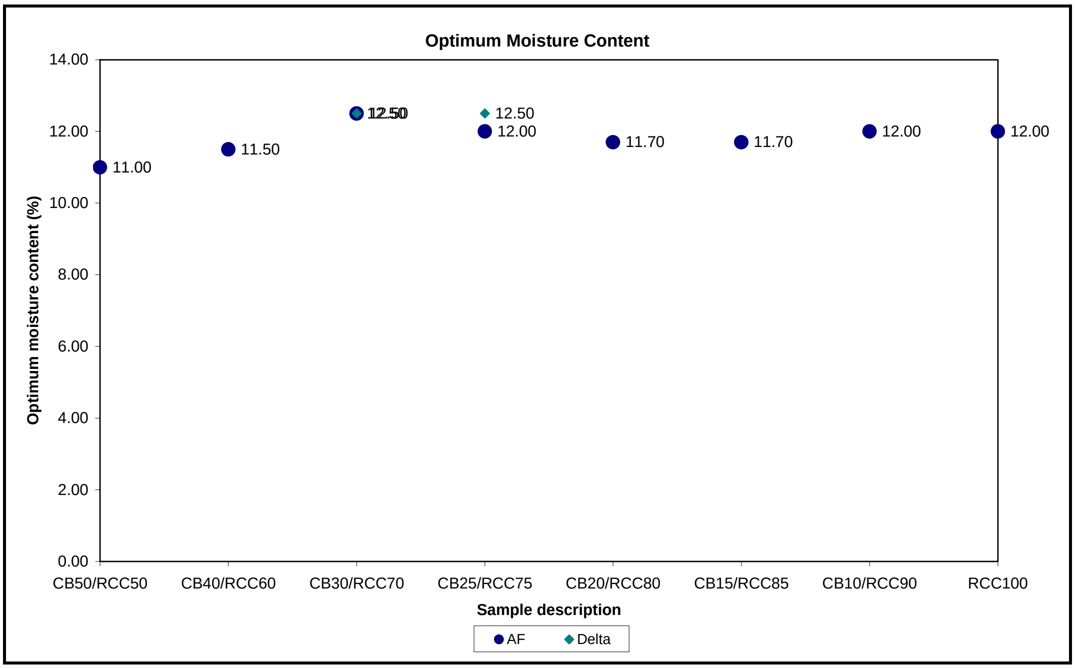

Figure 13: Optimum moisture content of crushed brick blended with crushed concrete (Class 3)

4.1.5 California Bearing Ratio (CBR)

The CBR values of all crushed brick and concrete blends were above 80%. This satisfies the VicRoads requirement on CBR for crushed concrete (Class 3) material. The CBR results of the crushed brick and concrete blends are presented in Figure 14.

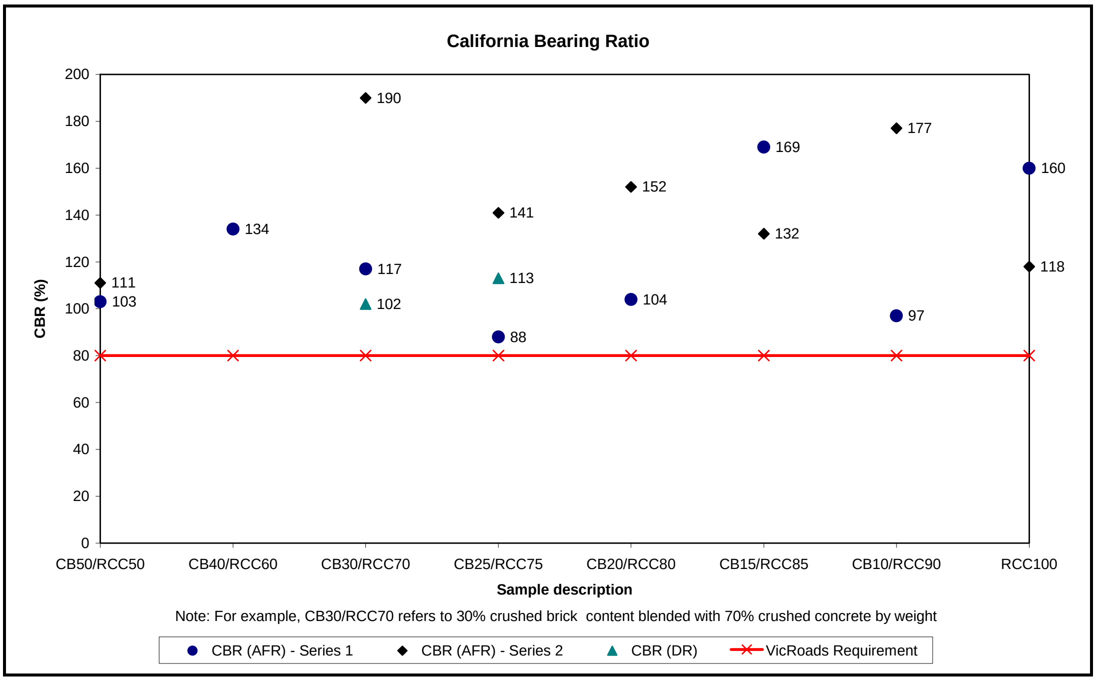

Figure 14: CBR of crushed brick blended with crushed concrete (Class 3)

4.1.6 pH

The pH values of all blends range between 10.60 to 11.50. This indicates that the blends are alkaline by nature. The pH results of the blends are presented in Figure 15.

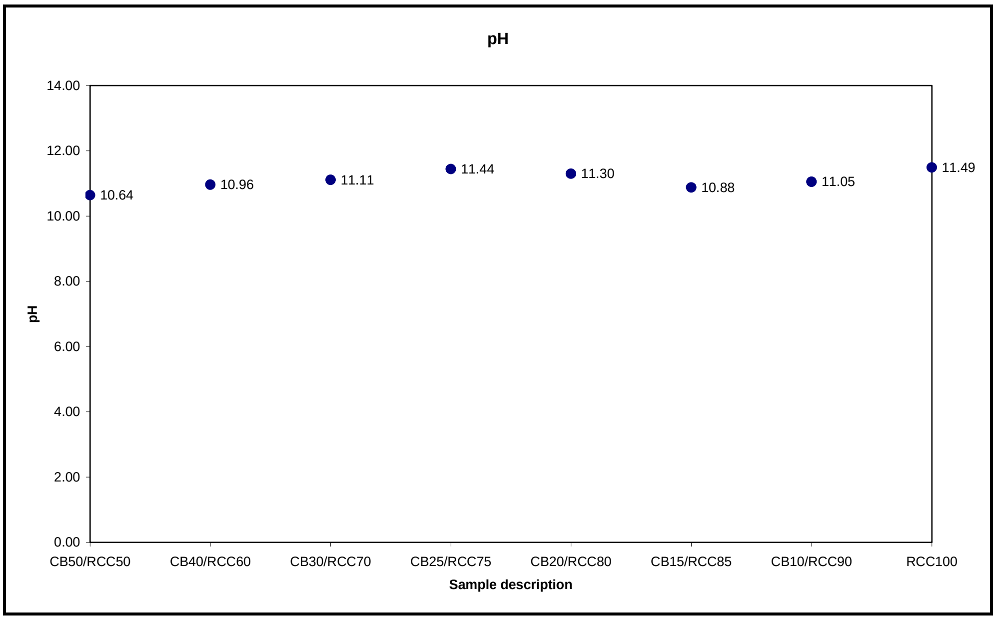

Figure 15: pH of crushed brick blended with crushed concrete (Class 3)

4.1.7 Fine Content

The fine content in all blends was less than 8%. The fine content results of the blends are presented in Figure 16.

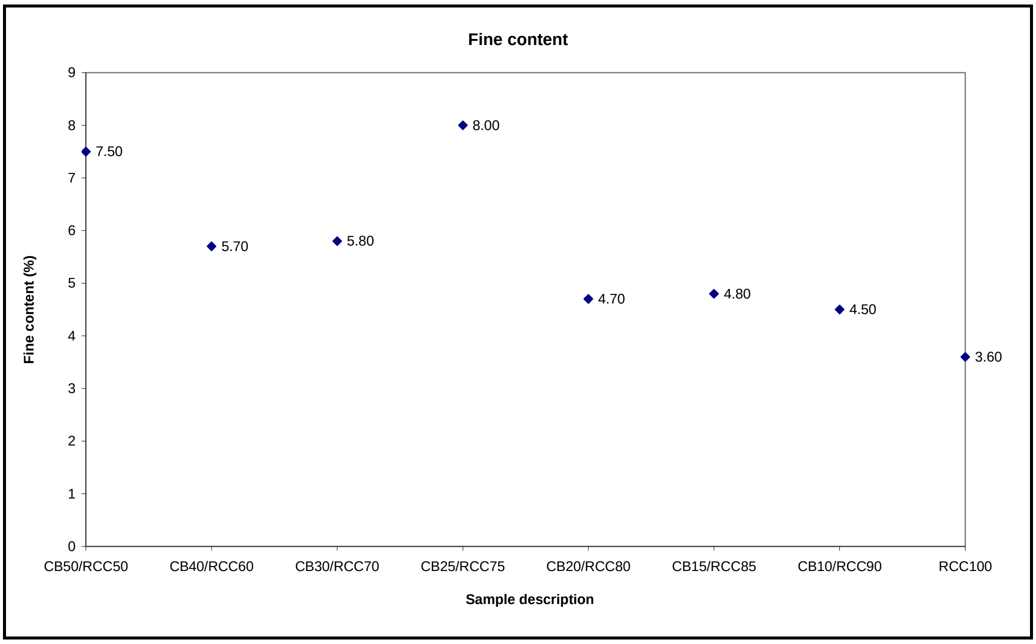

Figure 16: Fine content of crushed brick blended with crushed concrete (Class 3)

4.1.8 Plasticity Index

As the clay content in all the blends was low, the plastic limit and liquid limit could not be obtained. This is because the Atterberg limit is directly related to clay mineralogy and as such, higher clay contents result in higher plasticity. This aspect may mean that some difficulties may occur with the workability of the crushed concrete blends as cohesion of particles and a “tight” prepared surface is usually a sought after characteristic. A field trial of the crushed concrete would best determine the degree of difficulties that may be experienced.

4.1.9 Organic Content

The organic content of blends range between 2.1% to 2.5%. The organic content results of the blends are presented in Figure 17.

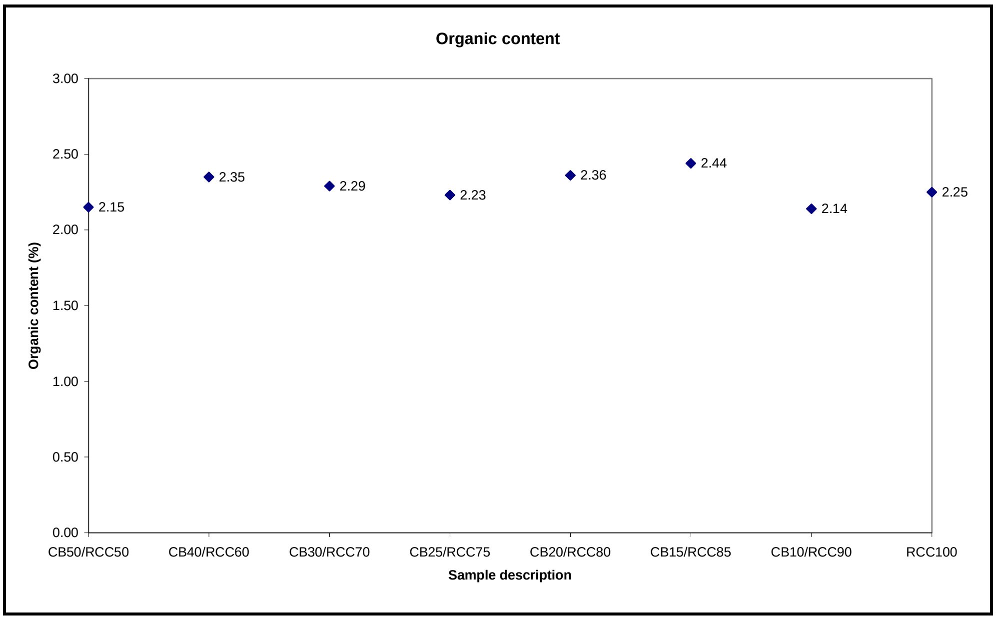

Figure 17: Organic content of crushed brick blended with crushed concrete (Class 3)

4.1.10 Los Angeles Abrasion loss

The Los Angeles Abrasion loss values of blends are between 28 to 33. The Los Angeles values of the blends are presented in Figure 18. These values are clearly within the maximum value of 35 normally adopted by VicRoads for Class 3 subbase pavement materials.

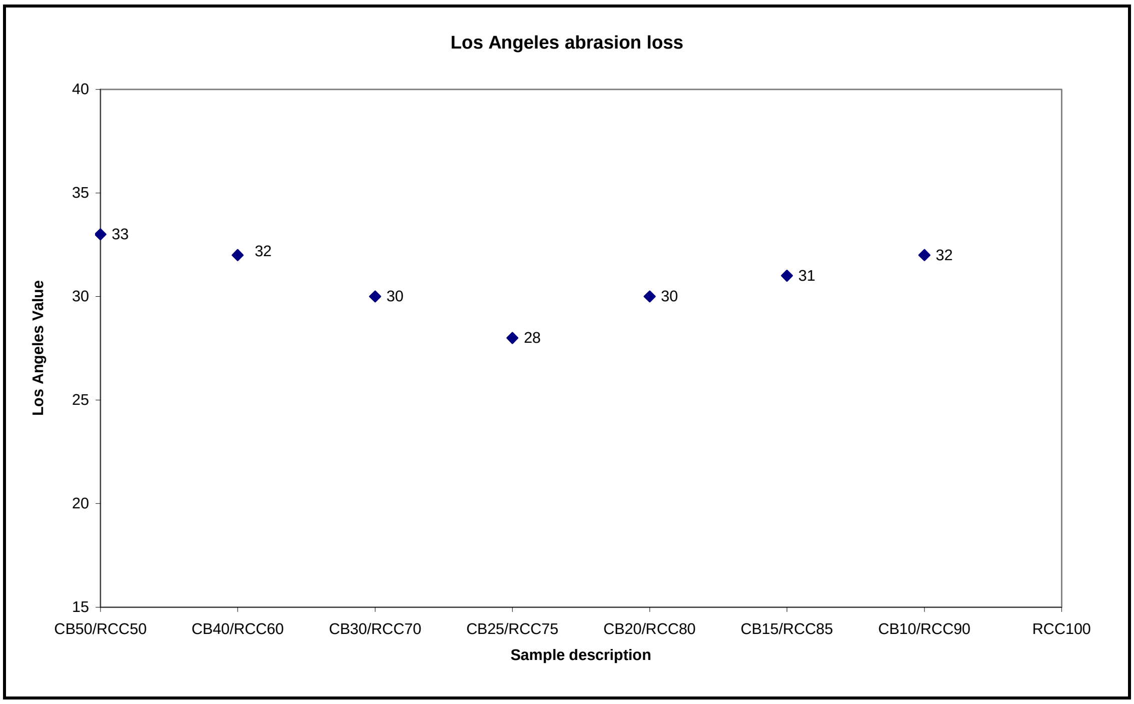

Figure 18: Los Angeles Abrasion loss of crushed brick blended with crushed concrete (Class 3)

4.1.11 Permeability

The coefficient of permeability results of the blends is 10^{-8} m/s. The coefficient of permeability values of the blends are presented in Figure 19. The permeability values determined fit within the maximum values normally specified by VicRoads for lesser trafficked roads.

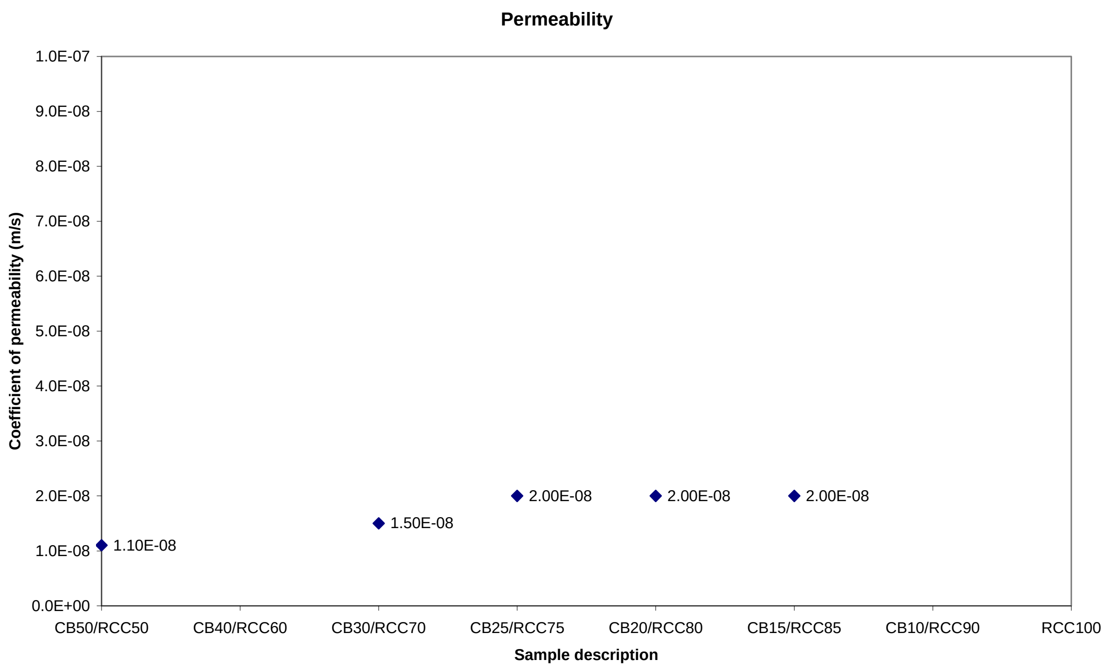

Figure 19: Permeability of crushed brick blended with crushed concrete (Class 3)

4.2 CRUSHED BRICK BLENDED WITH CRUSHED ROCK

Laboratory tests were performed on crushed brick blended with crushed rock (Class 3) obtained from the Alex Fraser Recycling site at Laverton as well as from the Delta Recycling site at Sunshine.

The particle size distribution prior to and after compaction results for crushed brick blended with crushed rock (Class 3) sourced from the Alex Fraser Recycling, Laverton site is summarised in Table 7 and Table 8. Table 9 summarises the engineering properties of crushed brick blended with crushed rock (Class 3) sourced from Alex Fraser Recycling, Laverton. Engineering properties of crushed brick blended with crushed rock (Class 3) sourced from Delta Recycling, Sunshine is summarised in Table 10. The differences in CBR results for the Series 1 and Series 2 tests could be due to slight differences in the aggregate strengths and proportions. The Series 1 tests and Series 2 tests were carried out on different bulk samples as they were carried out several months apart.

Table 7: Particle size distribution (before compaction)

Sample Description	CB50/ CR50	CB40/ CR60	CB30/ CR70	CB25/ CR75		CB20/ CR80		CB15/ CR85		CB10/ CR90		CR100	
Brick Content (%) by weight	50	40	30	25		20		15		10		0	
Particle size (mm)	Percentage of total passing (%)												
	Ser 1	Ser 1	Ser 1	Ser 1	Ser 2	Ser 1	Ser 2	Ser 1	Ser 2	Ser 1	Ser 2	Ser 1	Ser 2
26.5	100.0	100.0	100.0	100.0	100.0	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	98.7	98.8	97.7	99.7	99.4	99.3	99.5	100.0	98.9	97.4	99.1	99.3	99.1
13.2	82.2	81.2	82.7	90.4	88.7	89.7	87.2	89.0	88.1	76.8	87.7	89.7	86.4
9.50	69.1	66.3	74.8	82.1	77.1	77.9	76.7	77.8	75.2	65.8	77.2	81.9	74.2
4.75	46.4	44.5	52.2	57.8	52.1	51.1	52.2	53.4	50.6	44.2	51.6	55.3	48.0
2.36	33.4	31.2	38.4	42.5	36.9	37.9	36.6	39.2	35.3	33.3	35.2	39.0	32.2
0.075	7.4	7.2	10.1	10.7	8.8	9.6	9.6	9.9	9.2	8.8	8.9	10.2	8.6

Table 8: Particle size distribution (after compaction)

Sample Description	CB50/ CR50	CB40/ CR60	CB30/ CR70	CB25/ CR75	CB20/ CR80	CB15/ CR85	CB10/ CR90	CR100
Brick Content (%) by weight			30	25	20	15	10	0
Particle Size (mm)	Percentage of total passing (%)							
26.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	99.7	99.5	99.2	99.8	99.5	99.7	99.2	98.2
13.2	85.7	88.6	87.4	92.0	87.5	88.3	90.4	88.0
9.50	73.3	77.4	79.0	82.7	77.8	78.3	83.7	79.7
4.75	51.1	57.6	56.1	60.5	56.2	56.3	57.7	51.3
2.36	37.9	43.1	42.0	45.0	42.4	41.8	43.0	35.4
0.425	20.3	22.4	21.6	22.6	21.3	20.9	21.1	17.8
0.075	10.9	11.0	10.7	11.1	10.9	12.0	11.9	12.1

Table 9: Engineering properties of crushed brick blended with crushed rock (Class 3) – Alex Fraser Recycling, Laverton site

Sample Description		CB50/ CR50	CB40/ CR60	CB30/ CR70	CB25/ CR75	CB20/ CR80	CB15/ CR85	CB10/ CR90	CR100
Brick Content (%) by weight		50	40	30	25	20	15	10	0
Test description		Test results							
Particle density (Coarse)- Series 1(t/m^3)		2.67	2.71	2.72	2.75	2.78	2.78	2.76	2.78
Particle density (Coarse)- Series 2(t/m^3)					2.76	2.78			
Particle density (Fine) (t/m^3)					2.82	2.67			
Water absorption (Coarse) (%)- Series 1		4.15	3.90	3.75	3.38	3.05	2.83	3.24	3.32
Water absorption (Coarse) (%)- Series 2					3.80	3.10			
Water absorption (Fine) (%)					4.60	5.60			
CBR (%)	Series1	127	129	90	97	98	147	94	121
	Series2			131	143	168	167	176	174
Los Angeles abrasion		29	29	27	23	22	21	22	
Permeability (m/s)				9×10^{-8}	4×10^{-8}	4×10^{-8}	3.5×10^{-8}		
Organic content (%)		1.10	1.03	1.11	0.84	0.97	0.87	0.98	1.04
pH		9.76	9.83	9.65	9.74	9.87	10.80	9.78	10.92
Compaction (Modified)	Max dry density (t/m^3)	2.13	2.15	2.12	2.14	2.15	2.17	2.22	2.23
	Opt moisture content (%)	9.20	9.30	9.00	9.20	9.00	9.00	9.00	9.30
Atterberg Limit	Plastic limit	N.O	N.O	N.O	N.O	N.O	N.O	N.O	N.O
	Liquid limit	N.O	N.O	N.O	N.O	N.O	N.O	N.O	N.O
	Plasticity Index	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P
Fine content (%)		7.4	7.2	10.1	10.7	9.6	9.9	8.8	10.2
Flakiness Index		12	12	17	18	18	20	18	16

Table 10: Engineering properties of crushed brick blended with crushed rock (Class 3) – Delta Recycling, Sunshine site

Sample Description		CB30/CR70	CB25/CR75
Brick content (%) by weight		30	25
Test description		Test results	
Particle density (Coarse) (t/m^3)		2.77	2.82
Water absorption (Coarse) (%)(t/m^3)		3.73	3.56
CBR (%)		220	120
Max dry density (t/m^3)		2.20	2.22
Optimum moisture content (%)		8.5	8.5
Particle density	Sieve size	Total passing (%)	
	26.5mm	100.0	100.0
	19.0mm	99.7	99.5
	13.2mm	88.0	88.4
	9.50mm	79.5	77.9
	4.75mm	59.7	54.8
	2.36mm	48.6	43.5
	0.425mm	21.5	18.5
	0.075mm	9.7	8.9

4.2.1 Particle Size Distribution

The grading limits of all blends before and after compaction were found to be within the VicRoads specified lower and upper bound as presented in Figure 20, Figure 21 and Figure 22.

❖ **Before compaction**

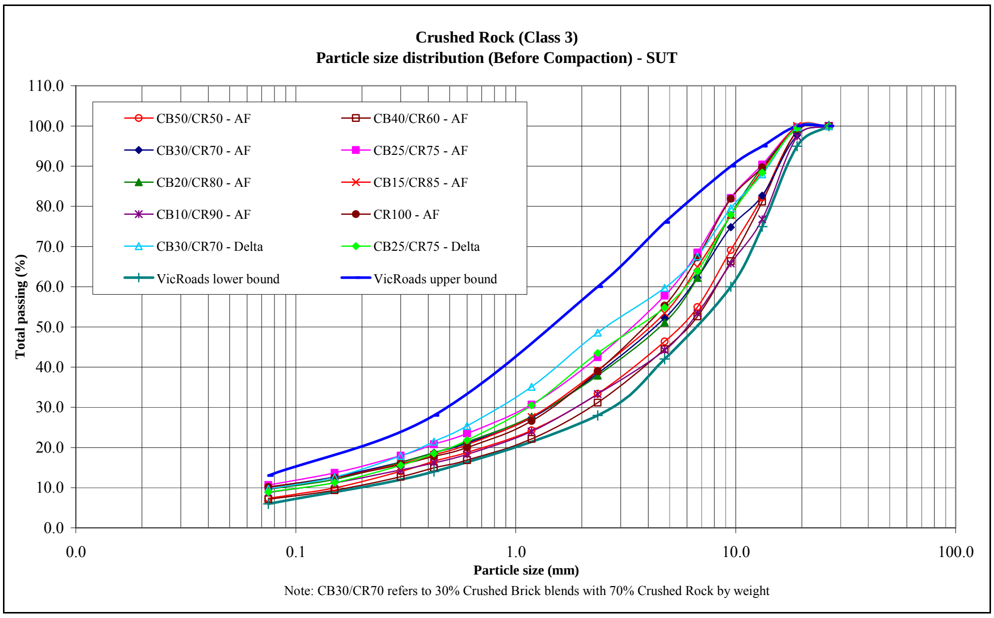

Figure 20: Particle size distribution (before compaction) for crushed brick blended with crushed rock (Class 3) – Series 1

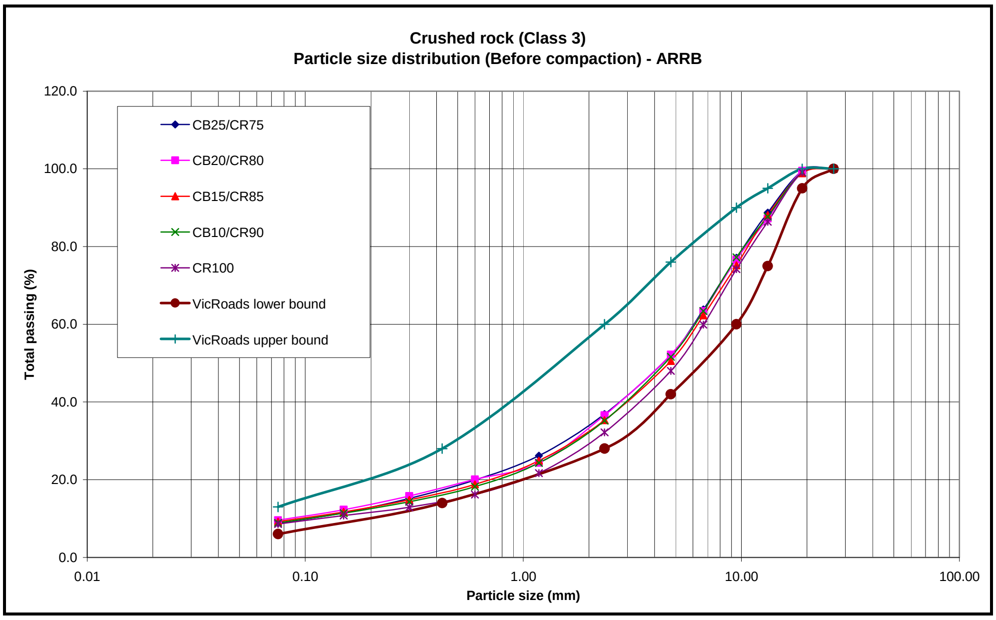

Figure 21: Particle size distribution (before compaction) for crushed brick blended with crushed rock (Class 3) – Series 2

❖ **After compaction**

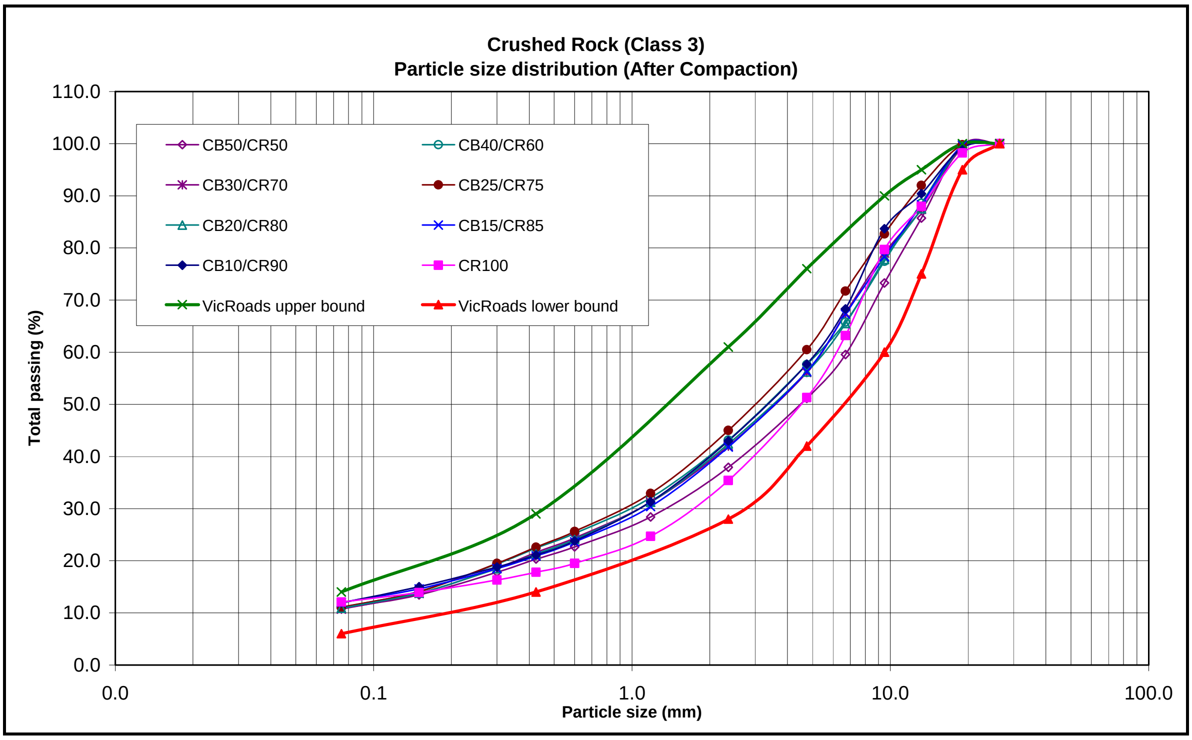

Figure 22: Particle size distribution (after compaction) for crushed brick blended with crushed rock (Class 3)

The before and after compaction gradings for the crushed rock blends show little breakdown is occurring during compaction other than that which is normally experienced with a standard subbase material. This would suggest that a higher limit of 20-25% crushed brick could be added to the crushed rock mixes without any significant loss of performance. The crushed rock blends appear to be remaining well graded through the compaction process and this will generally aid the compaction process.

4.2.2 Particle Density

❖ Coarse material

The particle densities of coarse blended aggregates passing 19 mm and retained on 4.75 mm range between 2.6 to 2.8. Particle density results for all blends are presented in Figure 23.

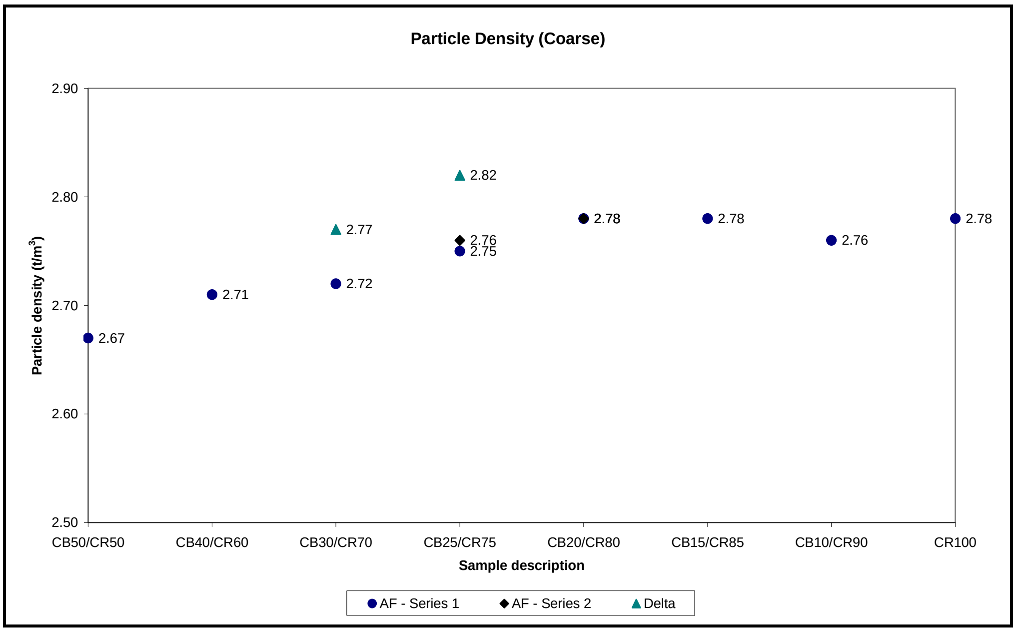

Figure 23: Particle density (coarse) of crushed brick blended with crushed rock (Class 3)

❖ Fine material

The particle densities of fine blended aggregates passing 4.75 mm range between 2.65 to 2.85 t/m^3. Particle density results for all blends are presented in Figure 24.

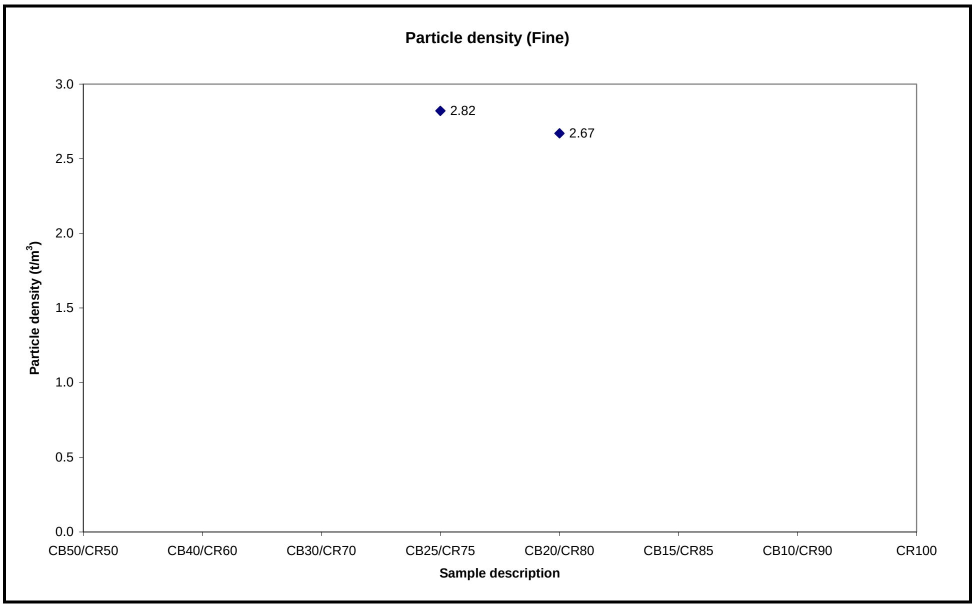

Figure 24: Particle density (fine) of crushed brick blended with crushed rock (Class 3)

4.2.3 Water Absorption

❖ Coarse material

The water absorptions of coarse blended aggregates passing 19 mm and retained on 4.75 mm range between 2.8% to 4.2%. Water absorption results for all blends are presented in Figure 25.

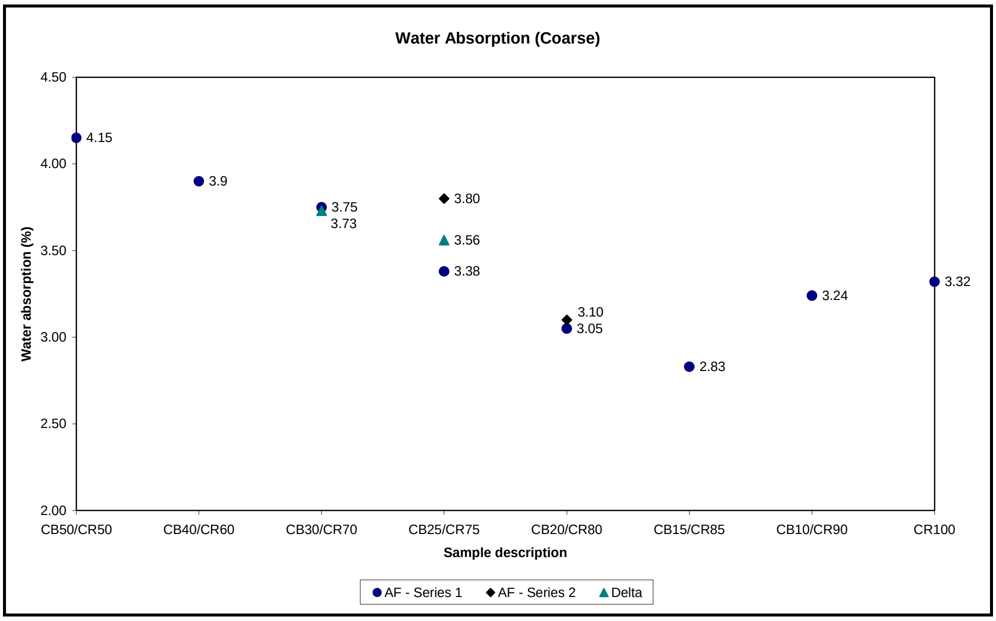

Figure 25: Water absorption (coarse) of crushed brick blended with crushed rock (Class 3)

❖ Fine material

The water absorptions of fine blended aggregates passing 4.75 mm range between 4% to 6%. Water absorption results for all blends are presented in Figure 26.

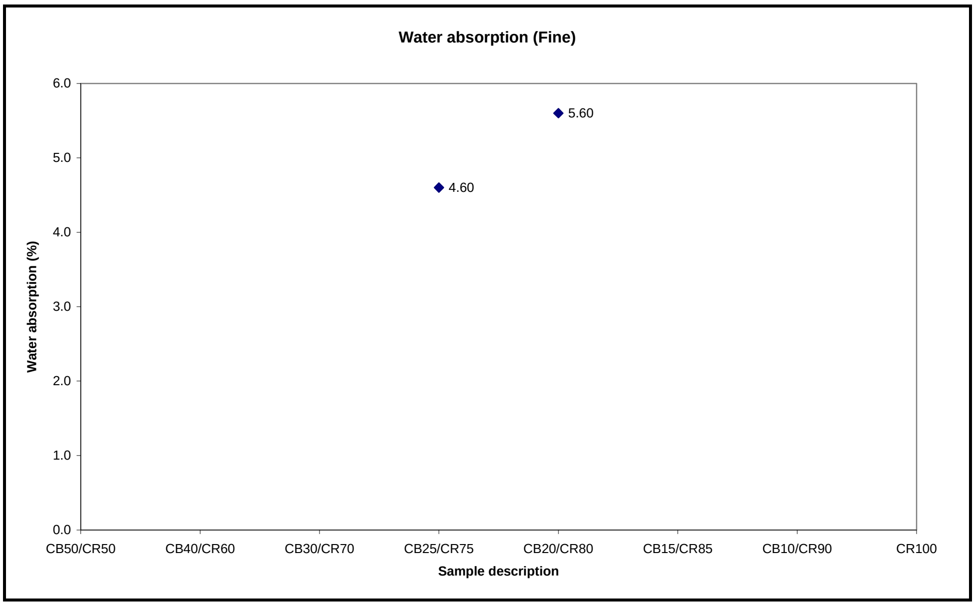

Figure 26: Water absorption (fine) of crushed brick blended with crushed rock (Class 3)

4.2.4 Modified Compaction

The maximum dry densities of blends following compaction range between 2.12 to 2.23 as presented in Figure 27. The optimum moisture content range between 8.5% to 9.3% and the results as shown in Figure 28.

❖ **Maximum dry density**

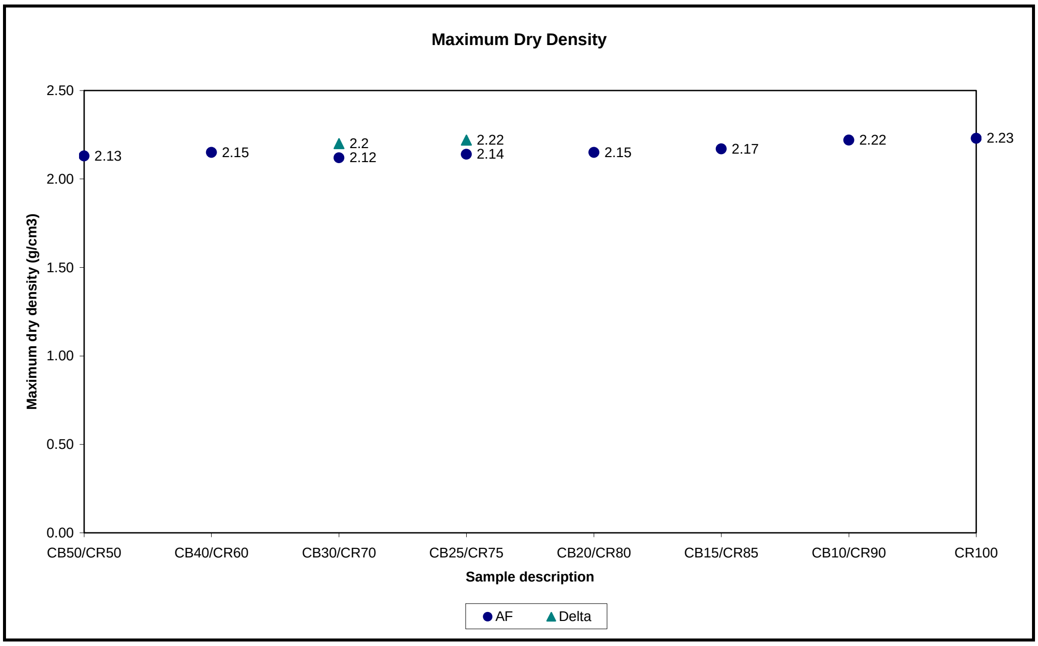

Figure 27: Maximum dry density of crushed brick blended with crushed rock (Class 3)

❖ **Optimum moisture content**

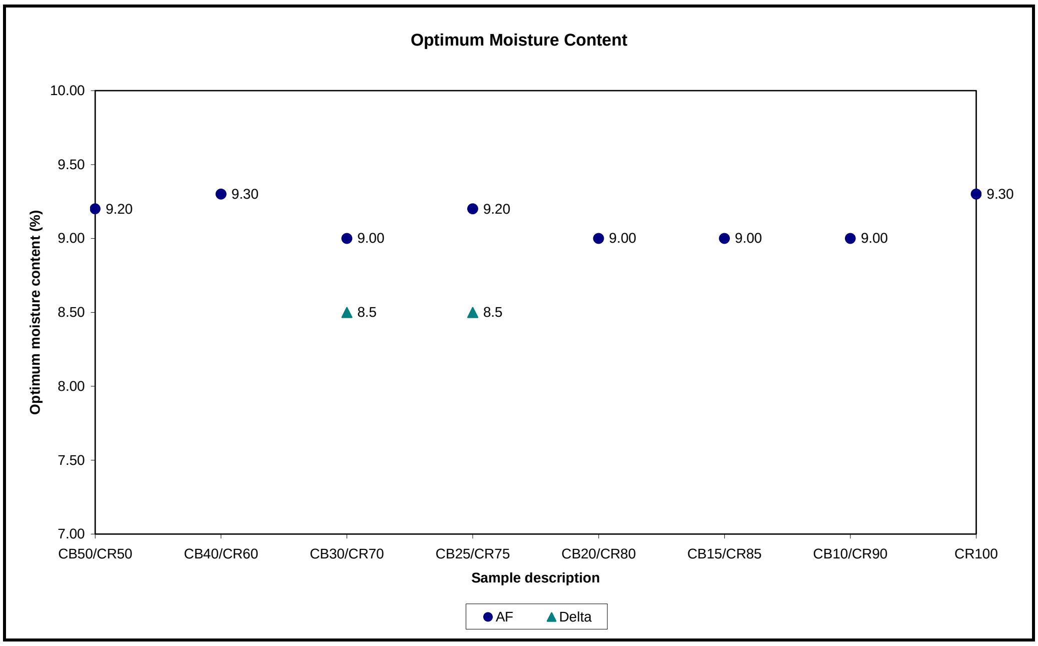

Figure 28: Optimum moisture content of crushed brick blended with crushed rock (Class 3)

4.2.5 California Bearing Ratio (CBR)

The CBR values of all crushed brick and crushed rock blends were above 90%. While VicRoads does not have a specific requirement in this regard for crushed rock (Class 3) material, the results achieved are acceptable and along with other test results indicate that the addition of varying percentages of crushed brick to the crushed rock blend has had little or no affect on the overall performance. The CBR results for the crushed brick and crushed rock blends are presented in Figure 29.

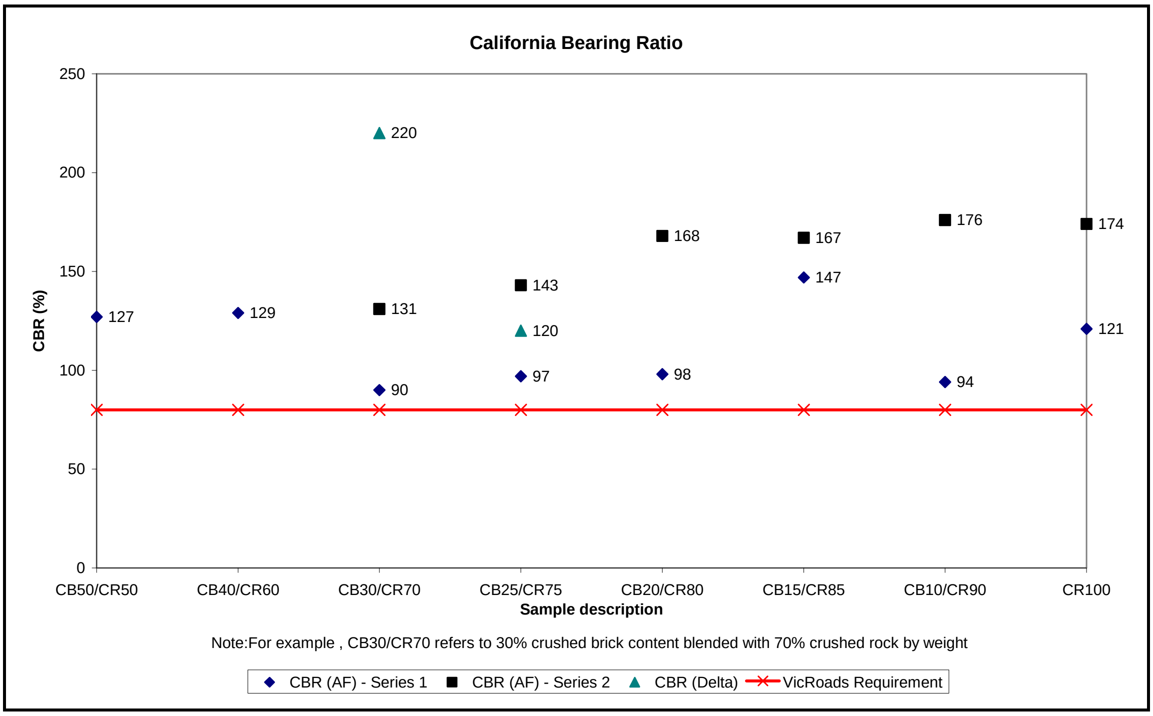

Figure 29: CBR values of crushed brick blended with crushed rock (Class 3)

4.2.6 pH

The pH values of all blends range between 9.7 to 11. It apparently indicates that the blends contain alkaline substances. The pH results of the blends are presented in Figure 30.

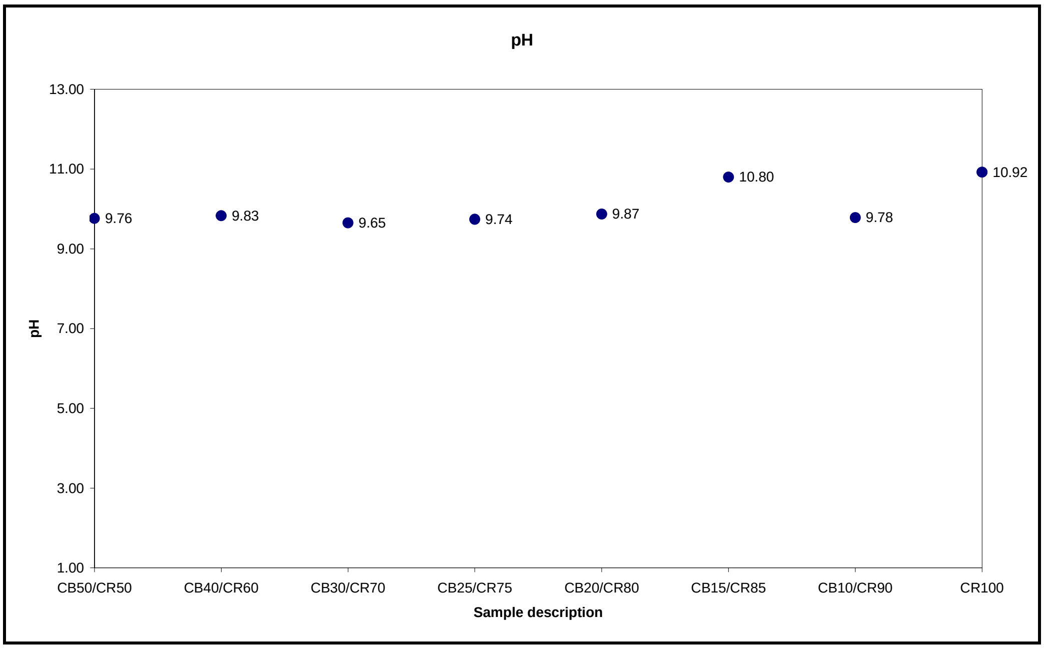

Figure 30: pH values of crushed brick blended with crushed rock (Class 3)

4.2.7 Fine Content

The fine content in all blends was less than 11%. The fine content results of the blends are presented in Figure 31.

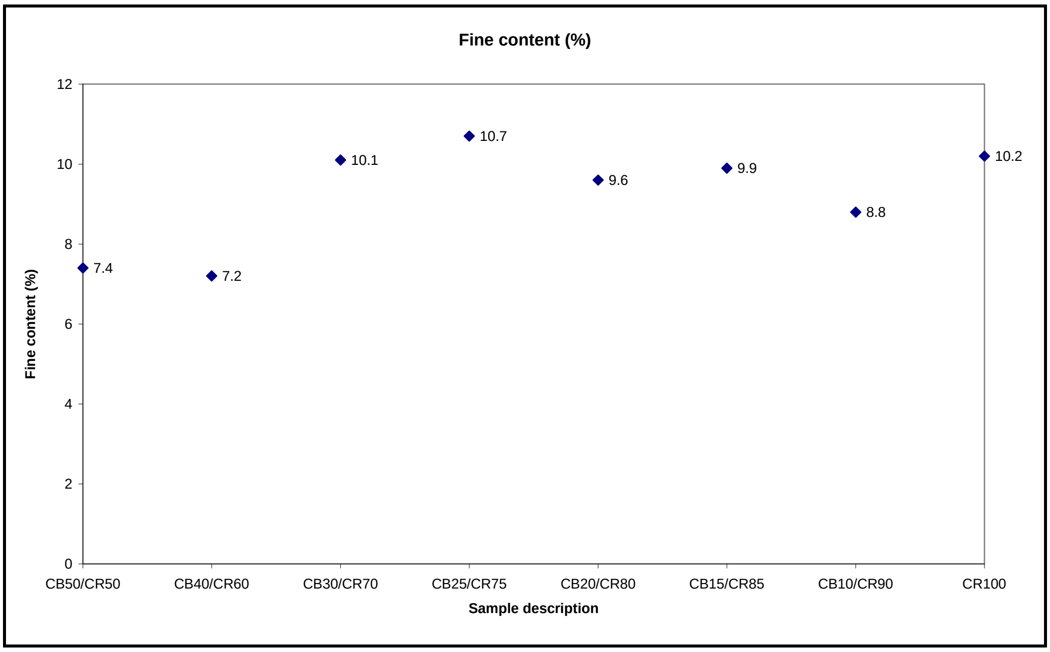

Figure 31: Clay content of crushed brick blended with crushed rock (Class 3)

4.2.8 Plasticity Index

As the clay content in all the blends was low, the plastic limit and liquid limit could not be obtained. This is because the Atterberg limit is directly related to clay mineralogy and as such, higher clay contents result in higher plasticity. As with the crushed concrete blends this aspect may mean that some difficulties may occur with the workability of the crushed rock blends as cohesion of particles and a "tight" prepared surface is usually a sought after characteristic. A field trial of the crushed rock blend would best determine the degree of difficulties that may be experienced.

4.2.9 Organic Content

The organic content of blends is less than 1.11%. The organic contents of the blends are presented in Figure 32.

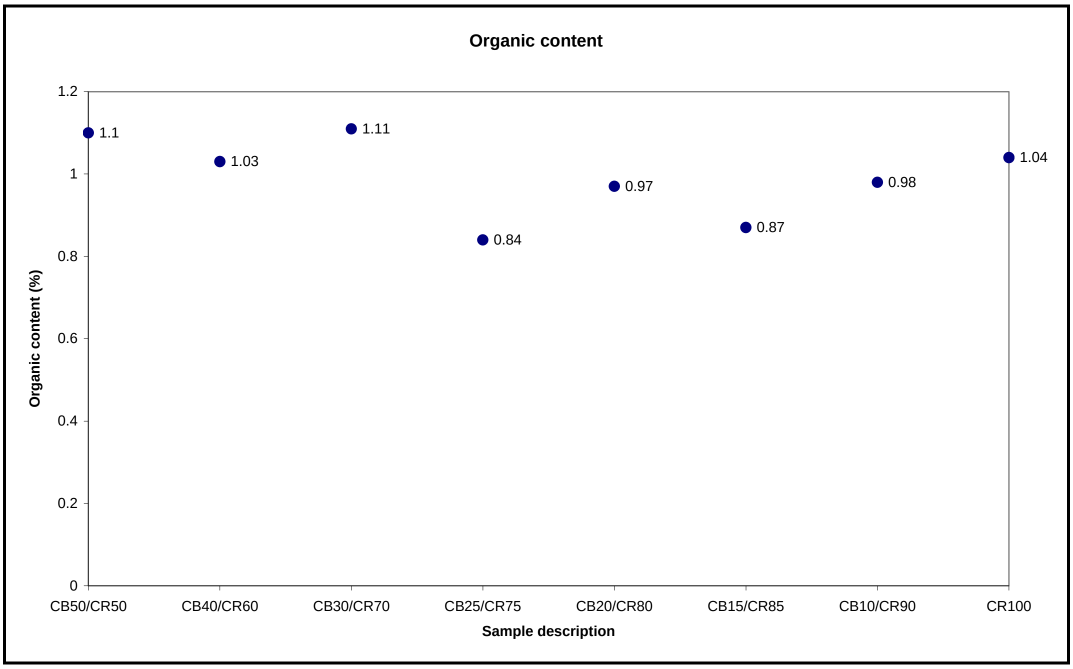

Figure 32: Organic content values of crushed brick blended with crushed rock (Class 3)

4.2.10 Los Angeles Abrasion loss

The Los Angeles values of blends range between 22 to 29. The Los Angeles values of the blends are presented in Table 33.

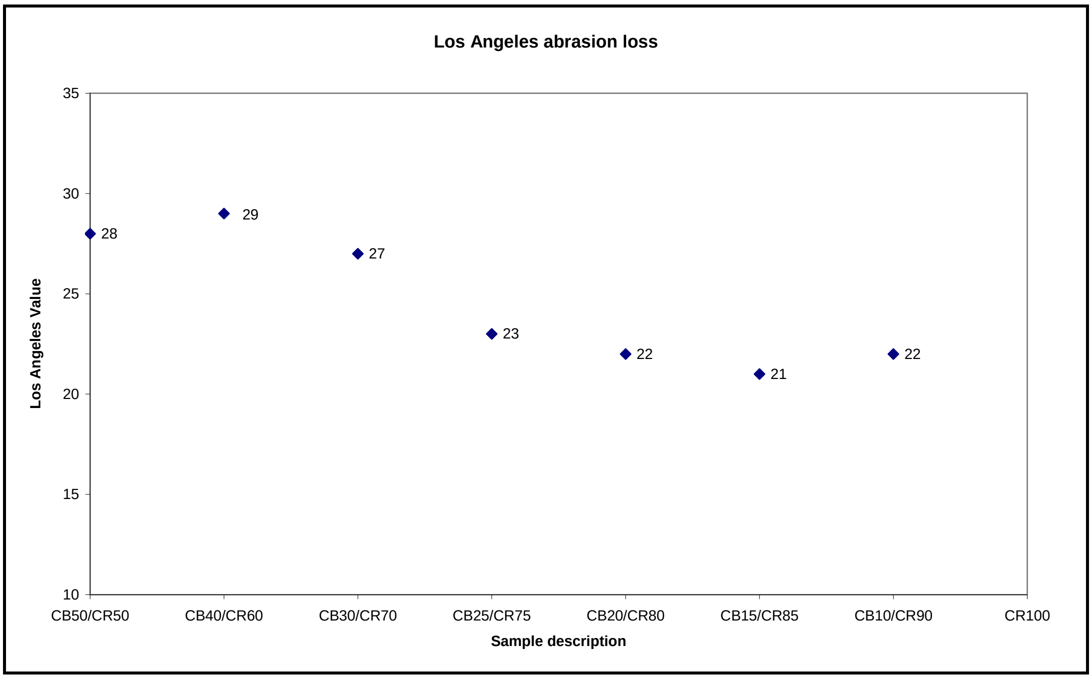

Figure 33: Los Angeles values of crushed brick blended with crushed rock (Class 3)

The Los Angeles Abrasion values achieved are well within the VicRoads required limit of "35" for a subbase pavement material.

4.2.11 Permeability

The coefficient of permeability values of blends is 10^{-8} m/s. The coefficient of permeability values are presented in Figure 34. The permeability values determined fit within the maximum values normally specified by VicRoads for lesser trafficked roads.

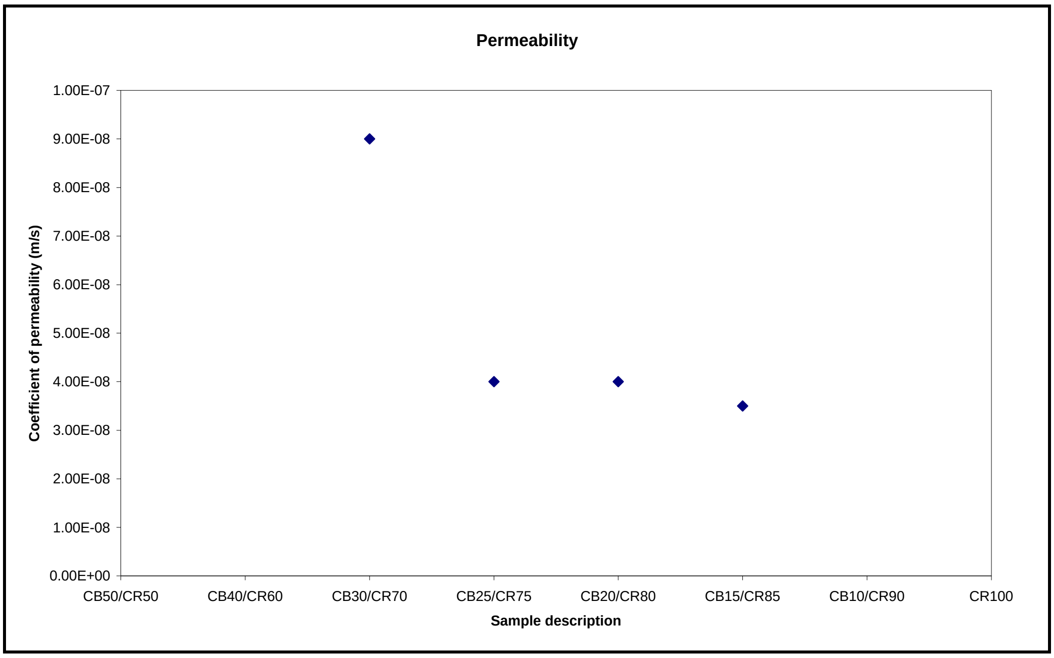

Figure 34: Permeability of crushed brick blended with crushed rock (Class 3)

5 RECYCLED CRUSHED GLASS

5.1 CRUSHED GLASS BLENDED WITH CRUSHED CONCRETE

Laboratory tests were performed on prepared samples of crushed glass blended with crushed concrete (Class 3) obtained from the Alex Fraser Recycling site at Laverton. The particle size distribution results prior to compaction and after compaction for crushed glass blended with crushed concrete (Class 3) sourced from the Alex Fraser Recycling, Laverton site is summarised in Table 11 and Table 12. Table 13 summarises the engineering properties of crushed glass blended with crushed concrete (Class 3) sourced from Alex Fraser Recycling, Laverton.

Table 11: Particle size distribution (before compaction)

Sample Description	RG50/ RCC50	RG40/ RCC60	RG30/ RCC70	RG20/ RCC80	RG15/ RCC85	RG10/ RCC90
Glass Content (%) by weight	50	40	30	20	15	10
Particle size (mm)	Percentage of total passing (%)					
26.5	100.0	100.0	100.0	100.0	100.0	100.0
19.0	99.7	99.7	99.4	100.0	100.0	99.4
13.2	92.3	92.0	91.1	90.0	88.2	92.2
9.5	87.1	85.8	82.6	78.4	76.2	83.2
4.75	76.0	73.7	67.4	59.7	58.2	64.6
2.36	56.8	54.6	50.6	44.4	43.7	50.1
0.075	5.8	6.6	6.5	6.9	6.8	8.6

Table 12 : Particle size distribution (after compaction)

Sample Description	RG50/ RCC50	RG40/ RCC60	RG30/ RCC70	RG20/ RCC80	RG15/ RCC85	RG10/ RCC90
Glass Content (%) by weight	50	40	30	20	15	10
Particle size (mm)	Percentage of total passing (%)					
26.5	100.0	100.0	100.0	100.0	100.0	100.0
19.0	100.0	100.0	100.0	100.0	100.0	100.0
13.2	94.8	95.4	92.5	93.9	92.5	89.4
9.5	90.5	90.6	85.1	85.5	85.4	79.4
4.75	80.5	77.8	71.2	68.3	68.0	60.7
2.36	63.1	61.6	56.3	54.1	54.0	47.4
0.425	23.3	23.8	23.2	23.8	25.5	22.5
0.075	8.2	8.5	8.7	8.9	10.0	8.9

The after compaction gradings show that some breakdown is occurring under compaction, however compliance with normal after compaction requirements is still achieved. It would be interesting to see what level breakdown occurs under a field compaction conditions and field trails are suggested to gauge the potential impacts.

Table 13: Engineering properties of crushed glass blended with crushed concrete (Class 3)

Sample Description		RG50/ RCC50	RG40/ RCC60	RG30/ RCC70	RG20/ RCC80	RG15/ RCC85	RG10/ RCC90	RCC100
Glass Content (%) by weight		50	40	30	20	15	10	0
Test description		Test results						
Particle density (Coarse)								2.72
Particle density (Fine)		2.47	2.58	2.58	2.61	2.60	2.65	2.68
Water absorption (Coarse) (%)								4.5
Water absorption (Fine) (%)		2.00	3.89	4.50	6.65	6.70	8.20	6.43
CBR (%)		98	110	120	144	176	203	
Los Angeles abrasion		30	28	30	31	32	32	28
Permeability (m/s)		3.6×10^{-7}					9×10^{-9}	
Organic content (%)		1.41	1.54	1.71	1.95	2.65	2.84	
pH		11.16	11.19	11.33	11.24	11.14	11.19	
Compaction (Modified)	Max dry density	1.90	1.97	1.96	1.93	1.96	1.98	
	Opt moisture content (%)	11.92	11.72	9.41	11.54	12.23	12.08	
Atterberg Limit	Plastic limit	N.O	N.O	N.O	N.O	N.O	N.O	N.O
	Liquid limit	N.O	N.O	N.O	N.O	N.O	N.O	N.O
	Plasticity Index	N.P	N.P	N.P	N.P	N.P	N.P	N.P
Fine content (%)		5.8	6.6	6.5	6.9	6.8	8.6	3.2
Flakiness Index*		N/A	N/A	N/A	N/A	N/A	N/A	11

*Note: Flakiness index test is not applicable to material passing a 6.30 mm BS test sieve or retained on a 63.0 mm BS test sieve.

5.1.1 Particle Size Distribution

The grading limits of all blends before and after compaction were found to be within the VicRoads specified lower and upper bound as presented in Figure 5, Figure 6 and Figure 7.

❖ **Before compaction**

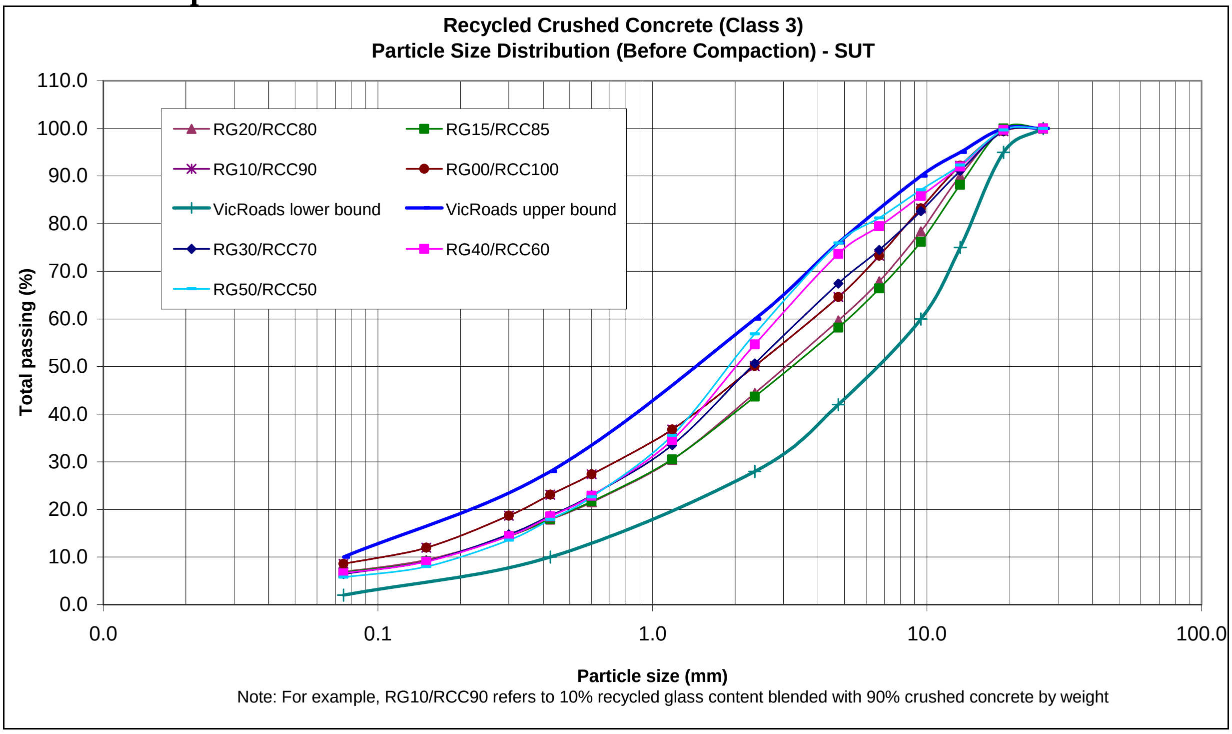

Figure 35: Particle size distribution (before compaction) for crushed glass blended with crushed concrete (Class 3)

❖ **After compaction**

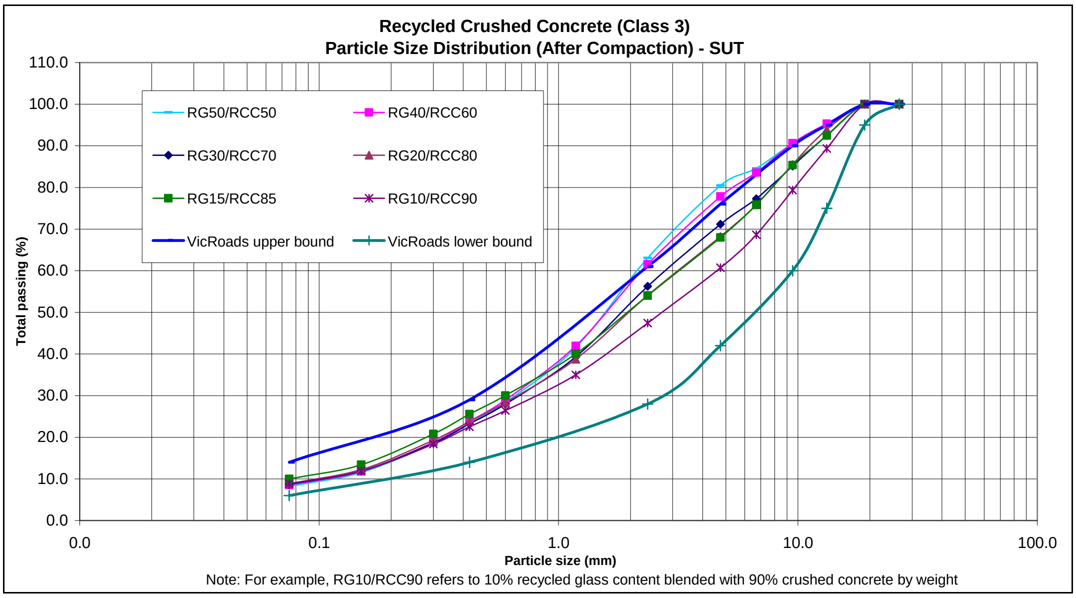

Figure 36: Particle size distribution (after compaction) for crushed glass blended with crushed concrete (Class 3)

The before and after compaction gradings of the random samples indicate that the materials appear to be remaining reasonably well graded through the compaction process and this will generally aid the compaction process.

Of importance is that most of the results are within the VicRoads specified lower and upper bounds. The results of after compaction grading curves for blends of 50% & 40% recycled concrete is on the VicRoads upper limits. The difference in the trends of the curves would be due to slight variations in the constitution of the samples.

5.1.2 Particle Density

❖ Coarse material

The particle density of coarse recycled crushed concrete passing 19 mm and retained on 4.75 mm is 2.72. Particle density result for recycled crushed concrete is presented in Figure 37.

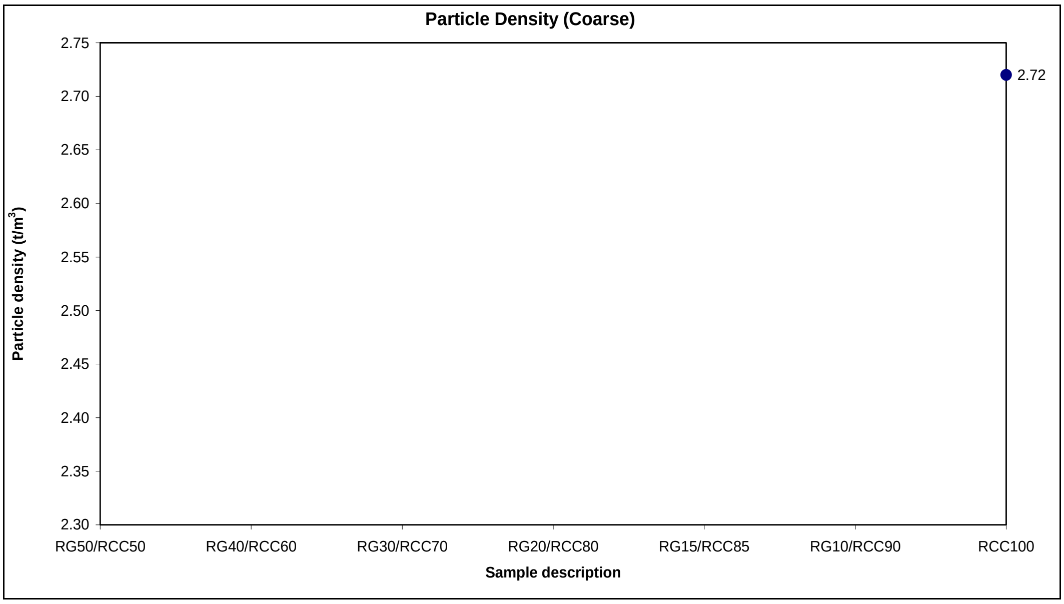

Figure 37: Particle density (coarse) of crushed glass blended with crushed concrete (Class 3)

❖ Fine material

The particle densities of fine blended aggregates passing 4.75 mm range between 2.47 to 2.65. Particle density results for all blends are presented in Figure 38.

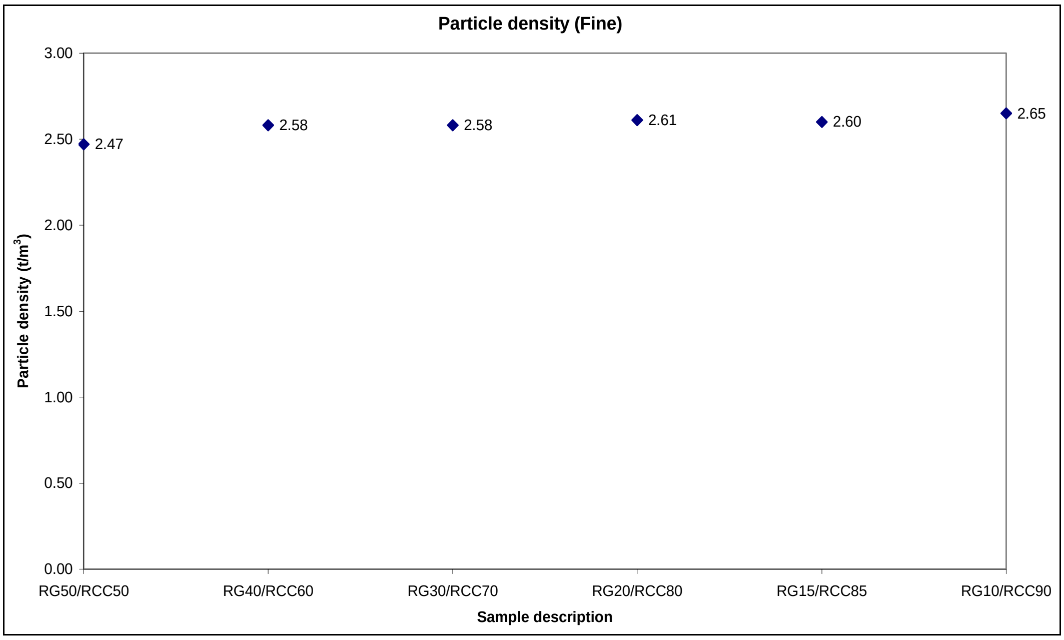

Figure 38: Particle density (fine) of crushed glass blended with crushed concrete (Class 3)

5.1.3 Water Absorption

❖ Coarse material

The water absorptions of coarse recycled crushed concrete passing 19 mm and retained on 4.75 mm is 4.5%. Water absorption result for recycled crushed concrete is presented in Figure 39.

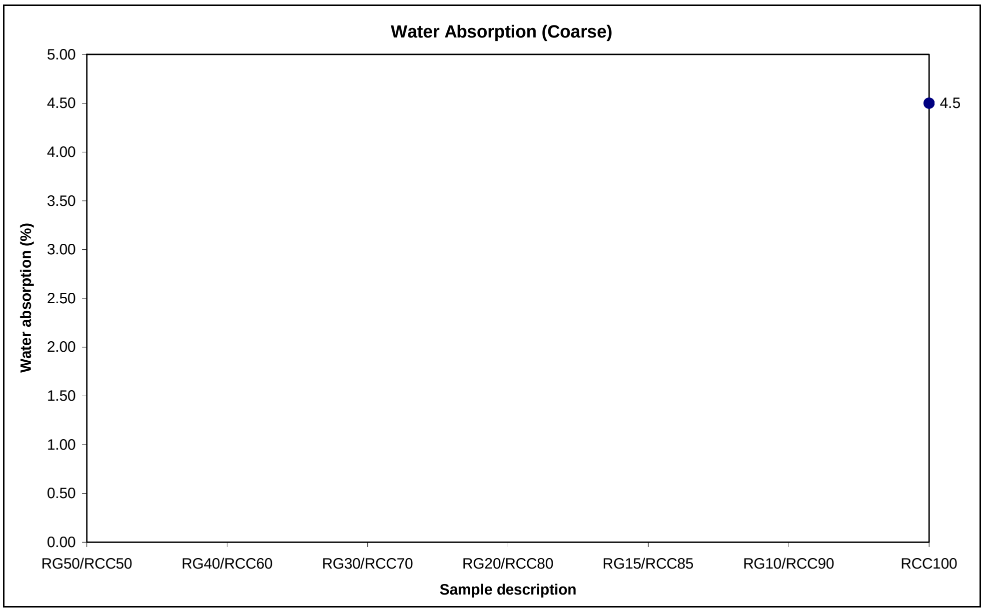

Figure 39: Water absorption (coarse) of crushed glass blended with crushed concrete (Class 3)

❖ Fine material

The water absorptions of fine blended aggregates passing 4.75 mm range between 2 % to 9 %. Water absorption results for all blends are presented in Figure 40.

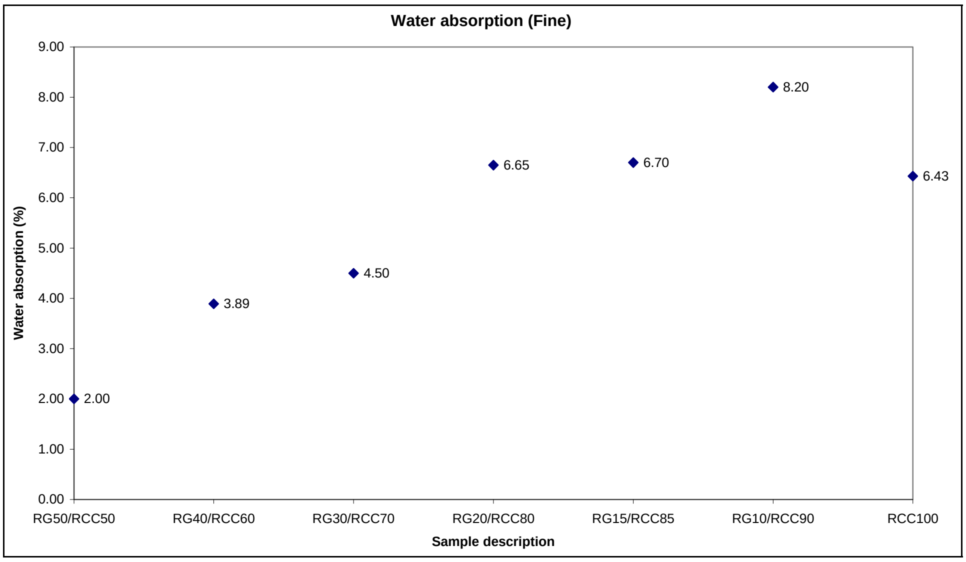

Figure 40: Water absorption (fine) of crushed glass blended with crushed concrete (Class 3).

The higher water absorption for the crushed concrete blends along with the generally higher optimum moisture contents will mean that the crushed concrete blends may be less attractive to contractors given the current difficulties in sourcing of suitable water sources for road construction activities.

5.1.4 Modified Compaction

The maximum dry densities of blends following compaction range between 1.90 to 1.98 as presented in Figure 41. The optimum moisture contents for blends range between 11.7% to 12.5% as shown in Figure 42.

- ❖ **Maximum dry density**

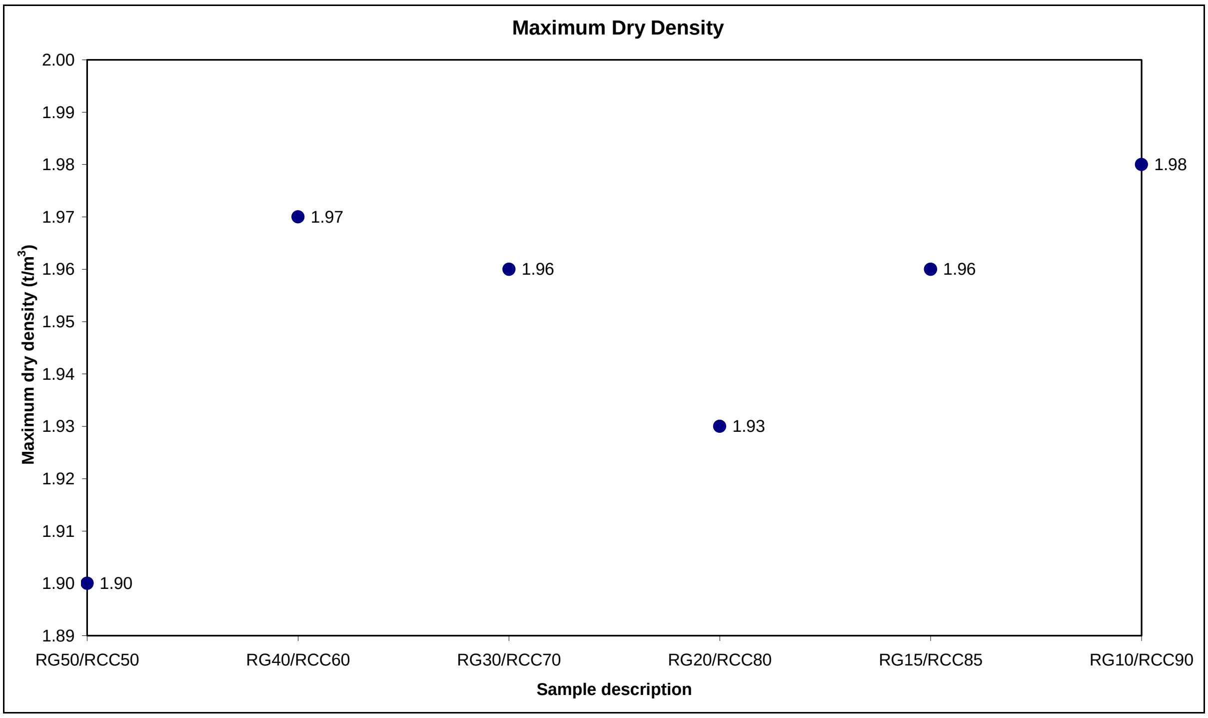

Figure 41: Maximum dry density of crushed glass blended with crushed concrete (Class 3)

❖ **Optimum moisture content**

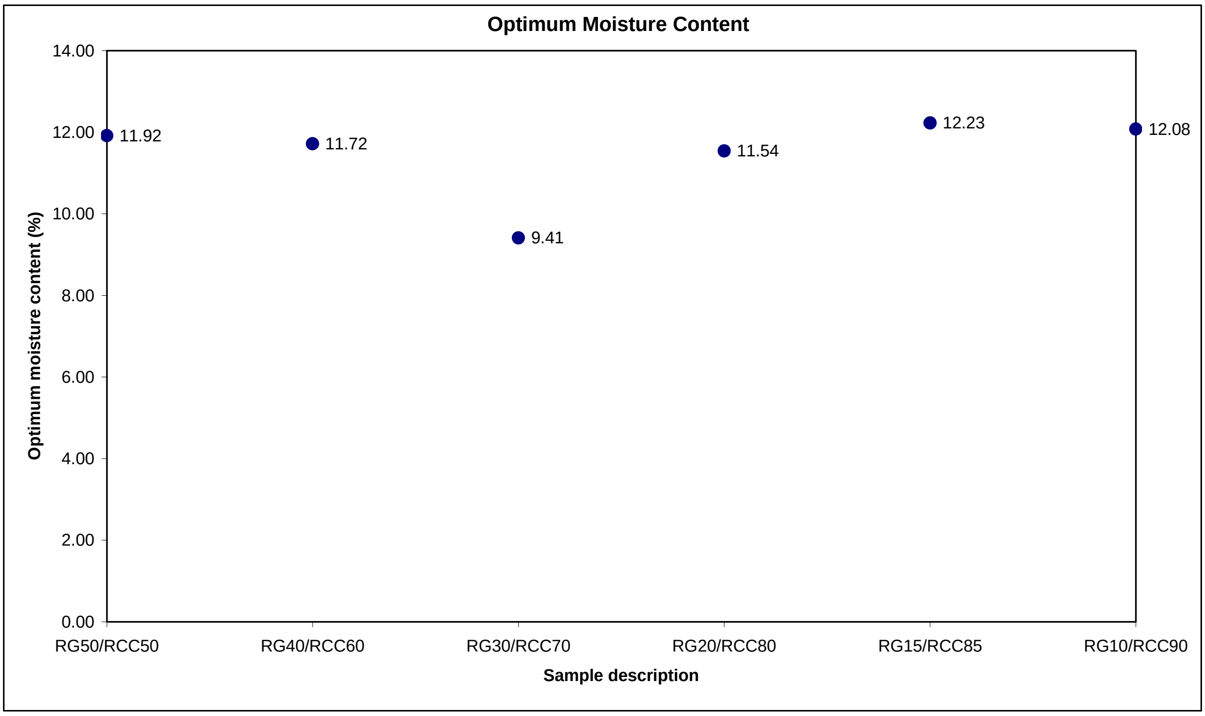

Figure 42: Optimum moisture content of crushed glass blended with crushed concrete (Class 3)

5.1.5 California Bearing Ratio (CBR)

The CBR values of all crushed glass and concrete blends were above 80%. This satisfies the VicRoads requirement on CBR for crushed concrete (Class 3) material. The CBR results of the crushed glass and concrete blends are presented in Figure 14.

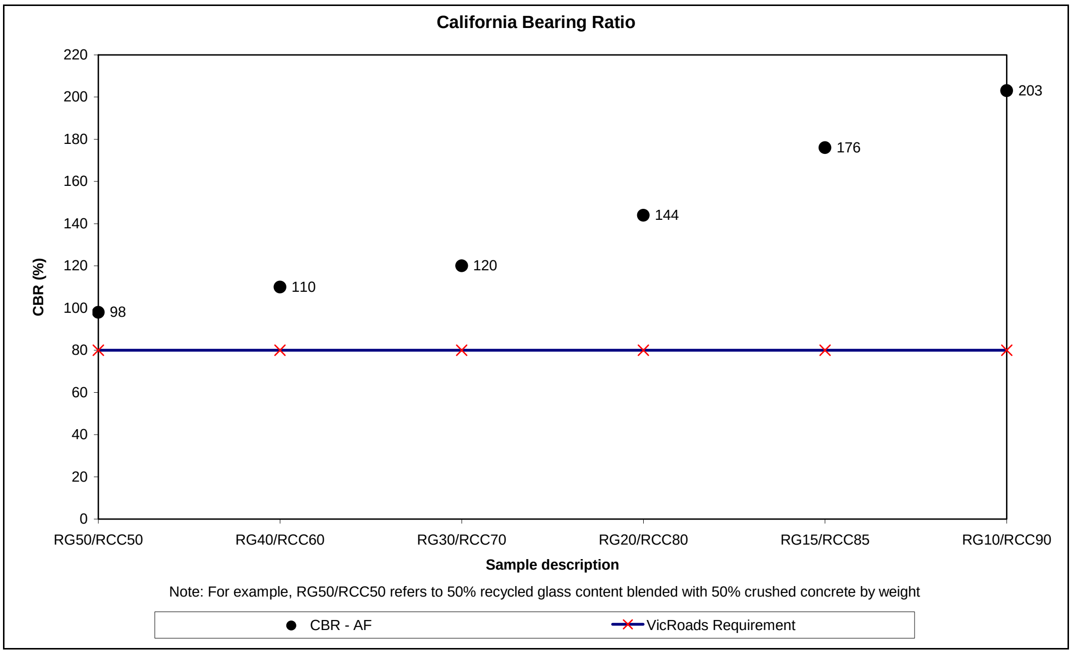

Figure 43: CBR of crushed glass blended with crushed concrete (Class 3)

5.1.6 pH

The pH values of all blends range between 11.00 to 11.50. This indicates that the blends are alkaline by nature. The pH results of the blends are presented in Figure 44.

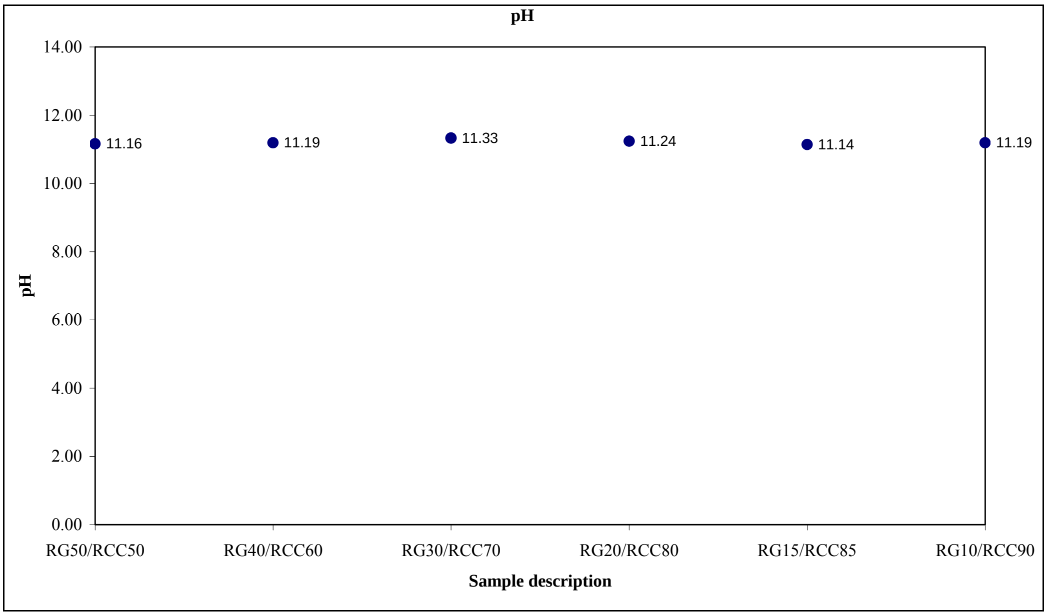

Figure 44: pH of crushed glass blended with crushed concrete (Class 3).

5.1.7 Fine Content

The fine content in all blends was less than 10%. The fine content results of the blends are presented in Figure 45.

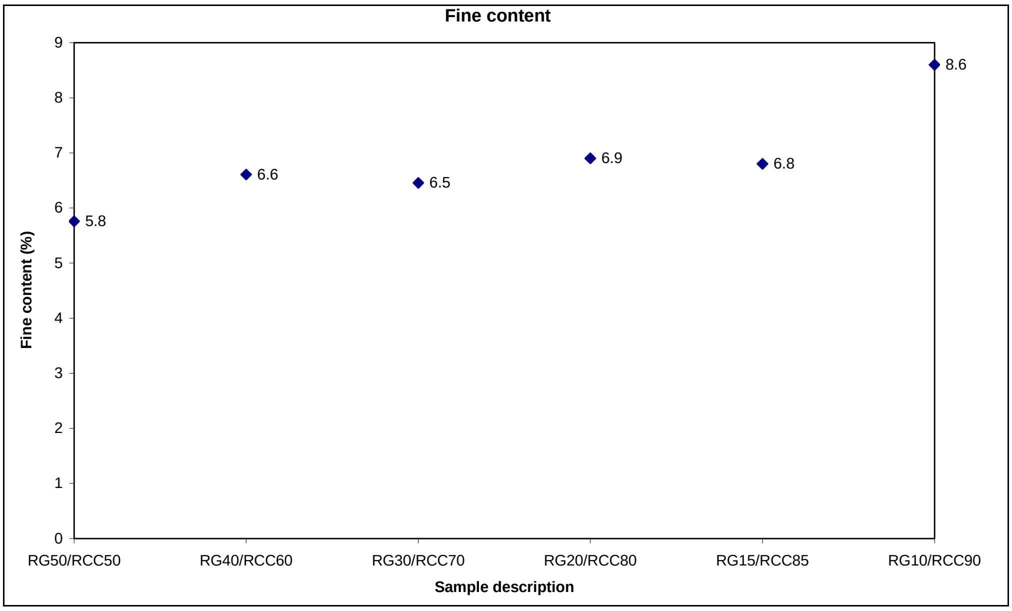

Figure 45: Fine content of crushed glass blended with crushed concrete (Class 3).

5.1.8 Plasticity Index

As the clay content in all the blends was low, the plastic limit and liquid limit could not be obtained. This is because the Atterberg limit is directly related to clay mineralogy and as such, higher clay contents result in higher plasticity. This aspect may mean that some difficulties may occur with the workability of the crushed concrete blends as cohesion of particles and a "tight" prepared surface is usually a sought after characteristic. A field trial of the crushed concrete would best determine the degree of difficulties that may be experienced.

5.1.9 Organic Content

The organic content of blends range between 1 % to 3 %. The organic content results of the blends are presented in Figure 46.

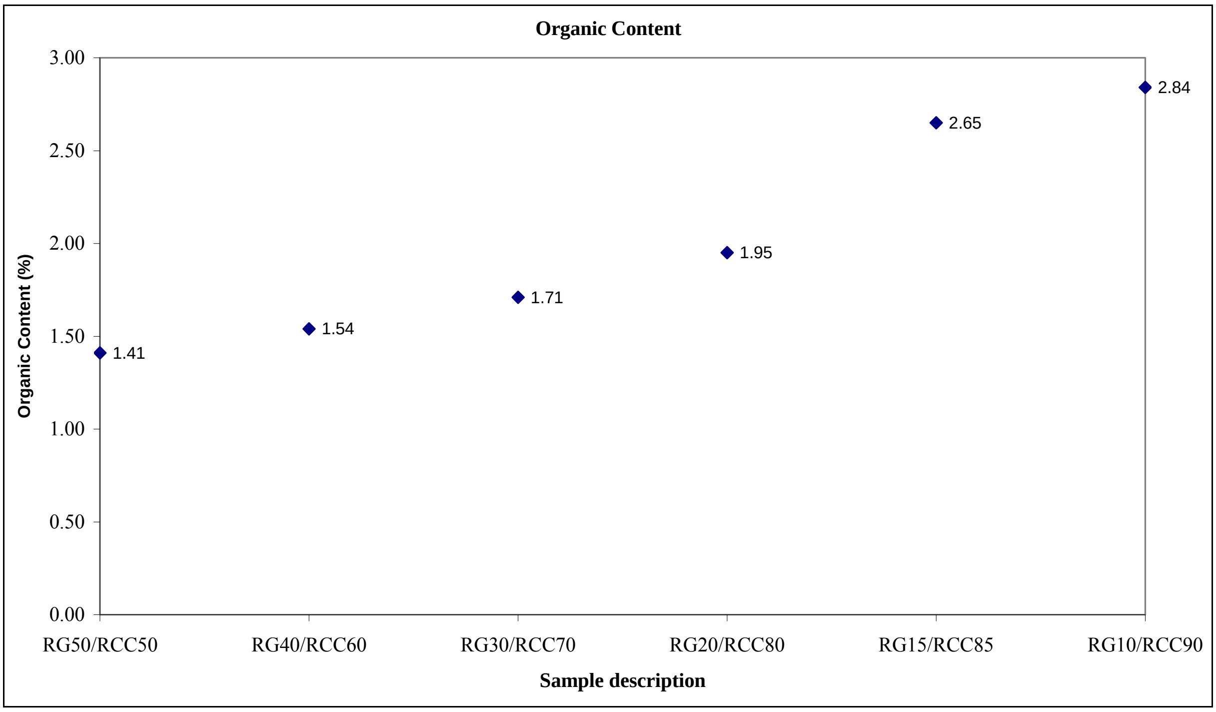

Figure 46: Organic content of crushed glass blended with crushed concrete (Class 3).

5.1.10 Los Angeles Abrasion loss

The Los Angeles Abrasion loss values of blends are between 28 to 32. The Los Angeles values of the blends are presented in Figure 47. These values are clearly within the maximum value of 35 normally adopted by VicRoads for Class 3 subbase pavement materials.

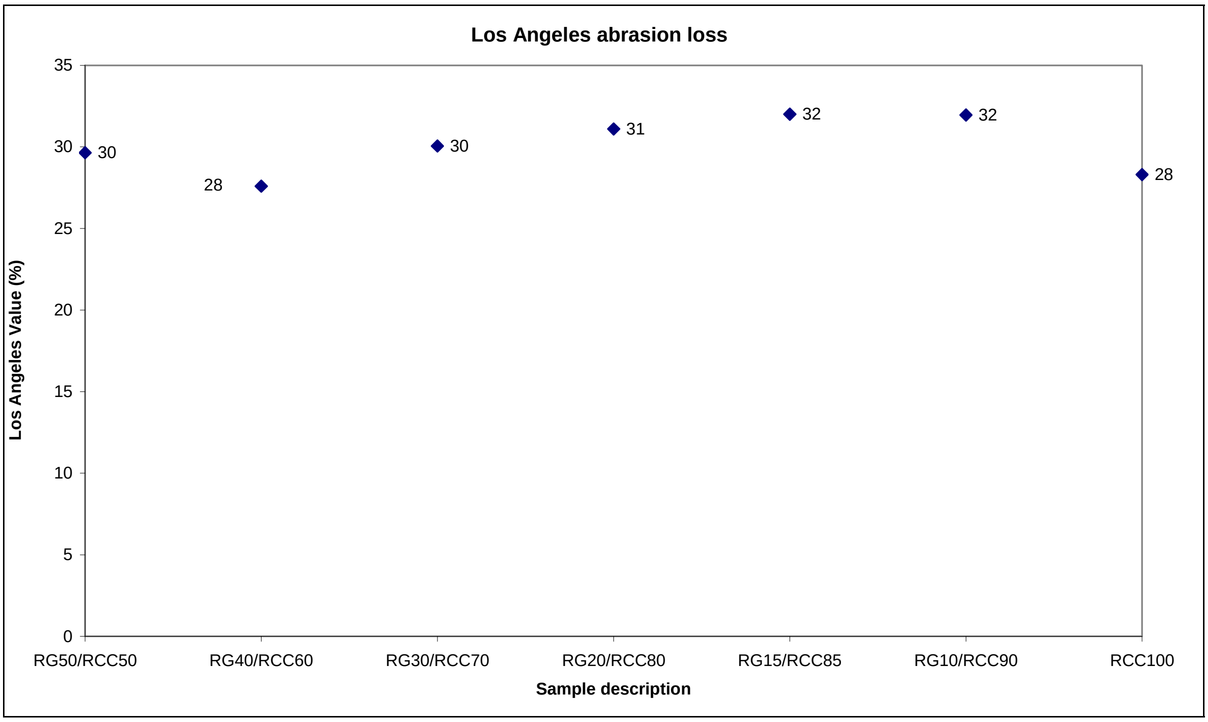

Figure 47: Los Angeles Abrasion loss of crushed glass blended with crushed concrete (Class 3).

5.1.11 Permeability

The coefficient of permeability results of the blends is 10^{-7} to 10^{-8}. The coefficient of permeability values of the blends are presented in Figure 48.

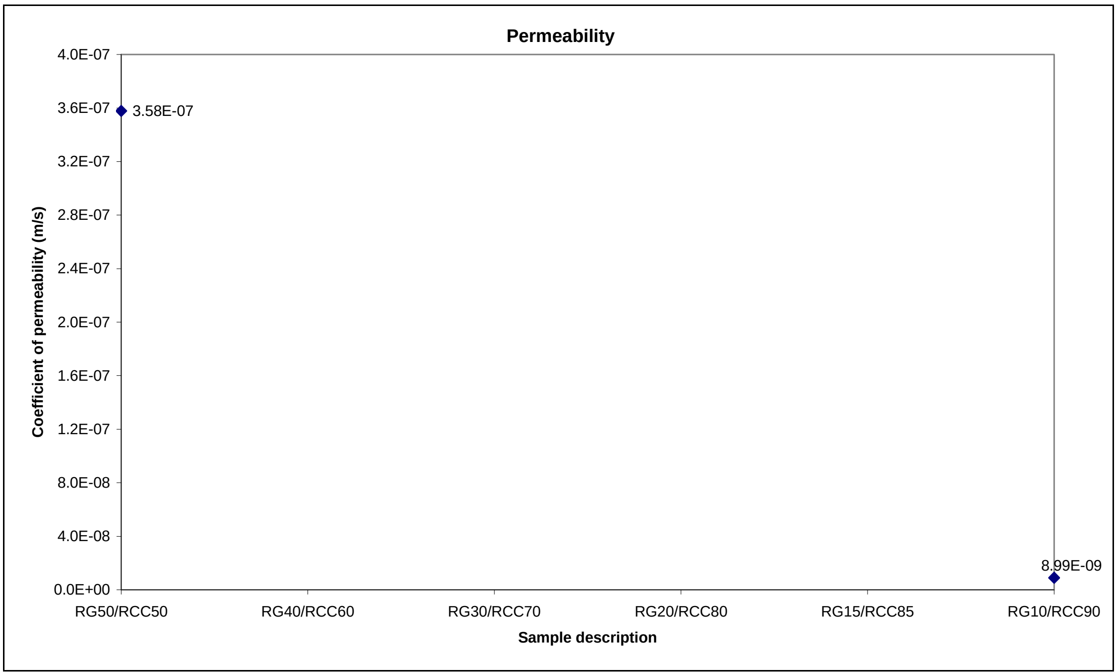

Figure 48: Permeability of crushed glass blended with crushed concrete (Class 3).

5.2 CRUSHED GLASS BLENDED WITH CRUSHED ROCK

Laboratory tests were performed on prepared samples of crushed glass blended with crushed rock (Class 3) obtained from the Alex Fraser Recycling site at Laverton. The particle size distribution results prior to compaction and after compaction for crushed glass blended with rock (Class 3) sourced from the Alex Fraser Recycling, Laverton site is summarised in Table 14 and Table 15. Table 16 summarises the engineering properties of crushed glass blended with crushed rock (Class 3) sourced from Alex Fraser Recycling, Laverton.

Table 14: Particle size distribution (before compaction)

Sample Description	RG50/ CR50	RG40/ CR60	RG30/ CR70	RG20/ CR80	RG15/ CR85	RG10/ CR90	CR100
Glass Content (%) by weight	50	40	30	20	15	10	0
Particle size (mm)	Percentage of total passing (%)						
26.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	98.8	99.3	99.3	99.0	98.1	96.8	100.0
13.2	93.2	92.7	88.4	86.8	86.4	84.2	92.7
9.5	89.4	88.0	80.8	79.4	79.2	74.4	83.5
4.75	80.1	75.4	67.9	63.8	63.4	59.3	62.7
2.36	56.6	52.1	49.0	44.2	45.7	42.4	48.5
0.075	8.1	8.8	9.2	9.9	10.9	10.5	3.2

Table 15 : Particle size distribution (after compaction)

Sample Description	RG50/ CR50	RG40/ CR60	RG30/ CR70	RG20/ CR80	RG15/ CR85	RG10/ CR90	CR100
Glass Content (%) by weight	50	40	30	20	15	10	0
Particle size (mm)	Percentage of total passing (%)						
26.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	99.5	100.0	99.7	99.3	99.7	99.8	100.0
13.2	92.2	93.4	87.3	91.5	89.3	87.5	86.1
9.5	86.5	87.9	81.2	83.8	81.1	79.9	76.4
4.75	77.5	76.8	69.5	69.0	64.5	63.0	57.9
2.36	60.0	58.5	53.4	52.4	48.6	47.5	43.4
0.425	20.6	20.7	20.8	21.1	21.0	21.4	21.2
0.075	9.1	8.4	10.8	11.8	11.9	12.6	13.2

The after compaction gradings show that some breakdown is occurring under compaction, however compliance with normal after compaction requirements is still achieved. It would be interesting to see what level breakdown occurs under a field compaction conditions and field trails are suggested to gauge the potential impacts.

Table 16: Engineering properties of crushed glass blended with crushed rock (Class 3)

Sample Description		RG50/ CR50	RG40/ CR60	RG30/ CR70	RG20/ CR80	RG15/ CR85	RG10/ CR90	CR100
Glass Content (%) by weight		50	40	30	20	15	10	0
Test description		Test results						
Particle density (Coarse)		2.77	2.76					2.80
Particle density (Fine)		2.61	2.65	2.71	2.79	2.75	2.80	2.87
Water absorption (Coarse) (%)		2.00	2.50					2.00
Water absorption (Fine) (%)		2.00	2.00	2.50	2.00	2.40	2.30	3.25
CBR (%)		121	137	152	165	199	170	181
Los Angeles abrasion		25	25	24	24	23	24	24
Permeability (m/s)		7.1×10^{-8}		6.0×10^{-8}		1.1×10^{-7}	1.7×10^{-7}	
Organic content (%)		0.60	0.58	0.62	0.72	0.72	0.78	0.66
pH		9.57	9.68	9.67	9.71	9.71	9.67	9.42
Compaction (Modified)	Max dry density	2.13	2.14	2.18	2.21	2.24	2.26	2.30
	Opt moisture content (%)	8.81	9.00	9.31	9.14	8.54	8.09	8.67
Atterberg Limit	Plastic limit	N.O	N.O	N.O	N.O	N.O	N.O	N.O
	Liquid limit	N.O	N.O	N.O	N.O	N.O	N.O	N.O
	Plasticity Index	N.P	N.P	N.P	N.P	N.P	N.P	N.P
Fine content (%)		8.1	8.8	9.2	9.9	10.9	10.5	3.2
Flakiness Index*		N/A	N/A	N/A	N/A	N/A	N/A	16

*Note: Flakiness index test is not applicable to material passing a 6.30 mm BS test sieve or retained on a 63.0 mm BS test sieve.

5.2.1 Particle Size Distribution

The grading limits of all blends before and after compaction were found to be within the VicRoads specified lower and upper bound as presented in Figure 49 and Figure 50.

❖ **Before compaction**

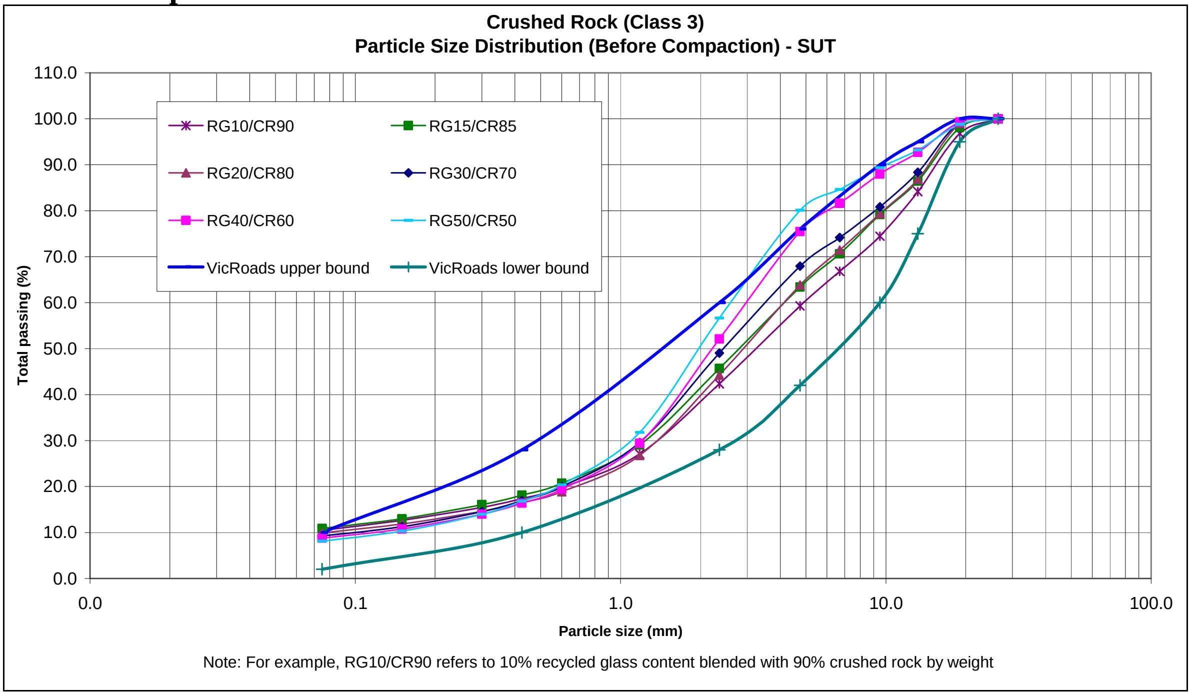

Figure 49: Particle size distribution (before compaction) for crushed glass blended with crushed rock (Class 3)

❖ **After compaction**

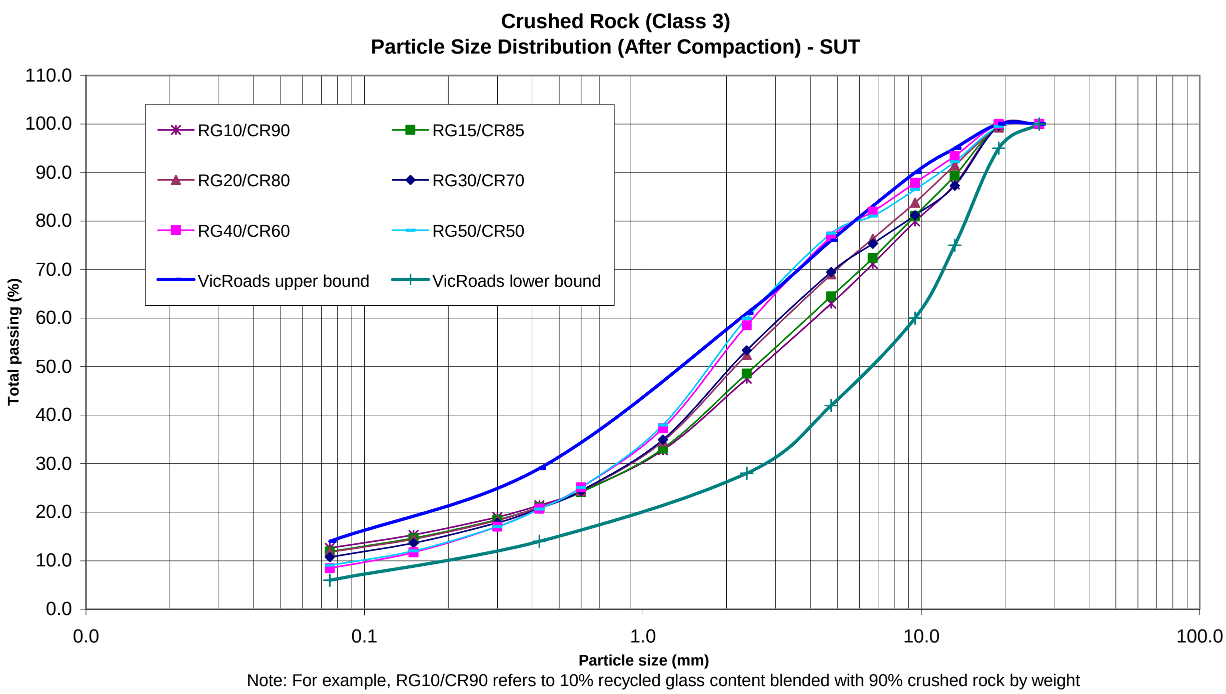

Figure 50: Particle size distribution (after compaction) for crushed glass blended with crushed rock (Class 3)

The before and after compaction gradings of the random samples indicate that the materials appear to be remaining reasonably well graded through the compaction process and this will generally aid the compaction process.

Of importance is that most of the results are within the VicRoads specified lower and upper bounds. The before & after compaction grading curves for blends of 50% crushed rock is on the VicRoads upper limits. The difference in the trends of the curves would be due to slight variations in the constitution of the samples.

5.2.2 Particle Density

❖ **Coarse material**

The particle densities of coarse blended aggregates passing 19 mm and retained on 4.75 mm range between 2.75 to 2.80. Particle density results for all blends are presented in Figure 51.

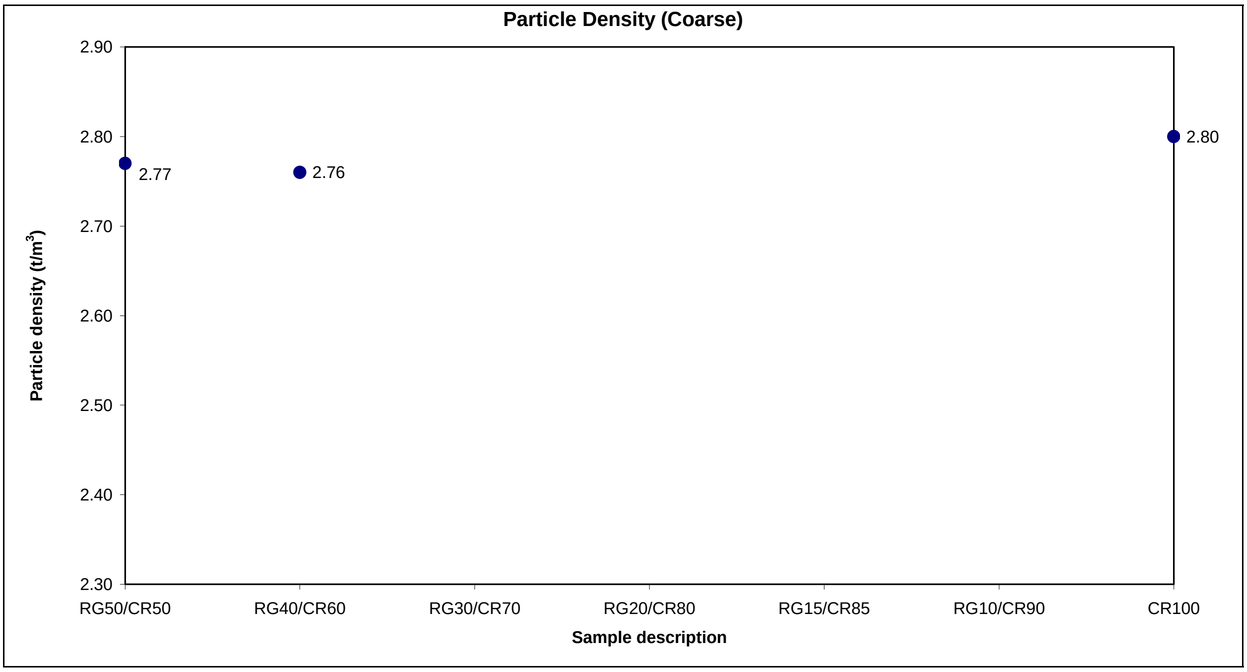

Figure 51: Particle density (coarse) of crushed glass blended with crushed rock (Class 3)

❖ **Fine material**

The particle densities of fine blended aggregates passing 4.75 mm range between 2.6 to 2.8. Particle density results for all blends are presented in Figure 52.

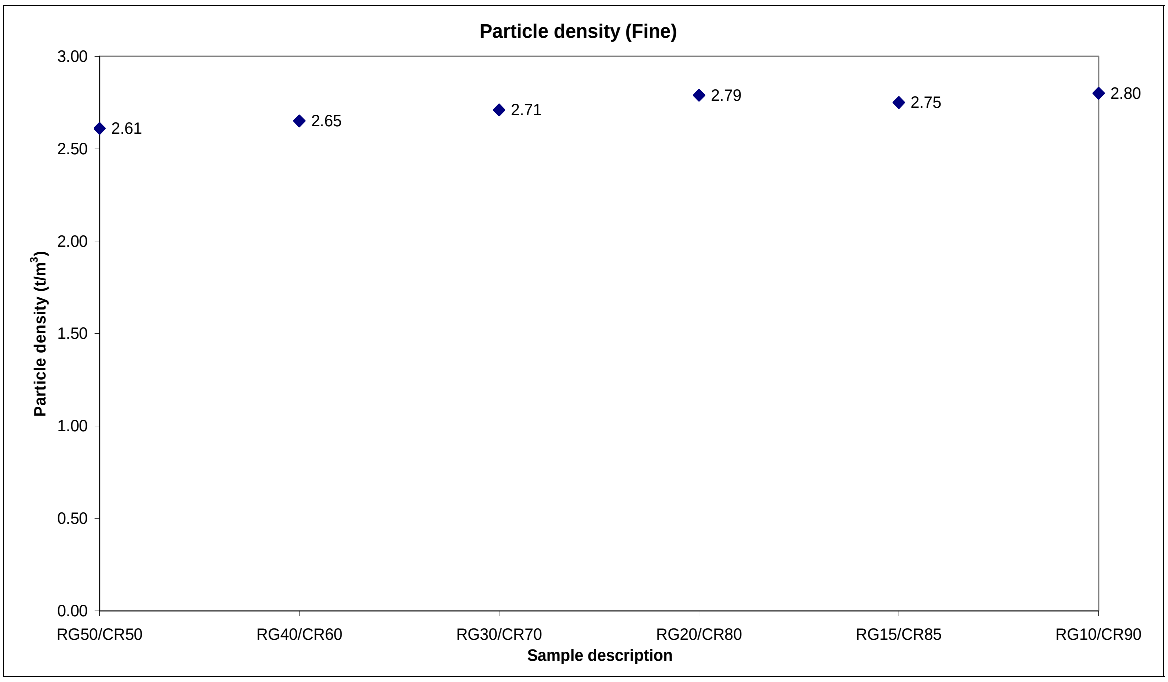

Figure 52: Particle density (fine) of crushed glass blended with crushed rock (Class 3)

5.2.3 Water Absorption

❖ **Coarse material**

The water absorptions of coarse blended aggregates passing 19 mm and retained on 4.75 mm range between 2% to 2.5%. Water absorption results for all blends are presented in Figure 53.

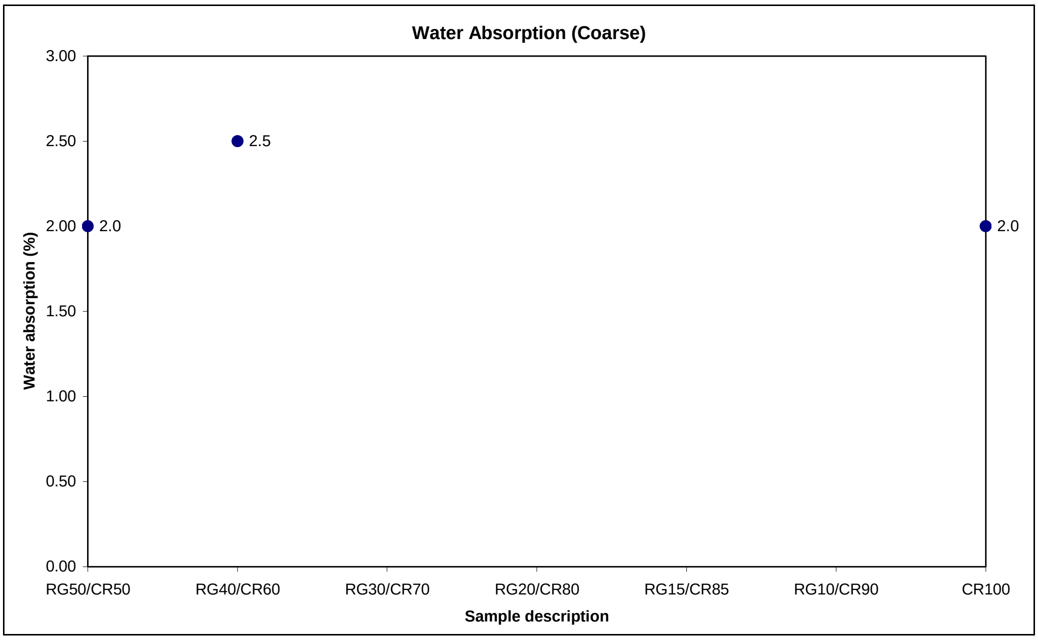

Figure 53: Water absorption (coarse) of crushed glass blended with crushed rock (Class 3)

❖ **Fine material**

The water absorptions of fine blended aggregates passing 4.75 mm range between 2 % to 2.5 %. Water absorption results for all blends are presented in Figure 54.

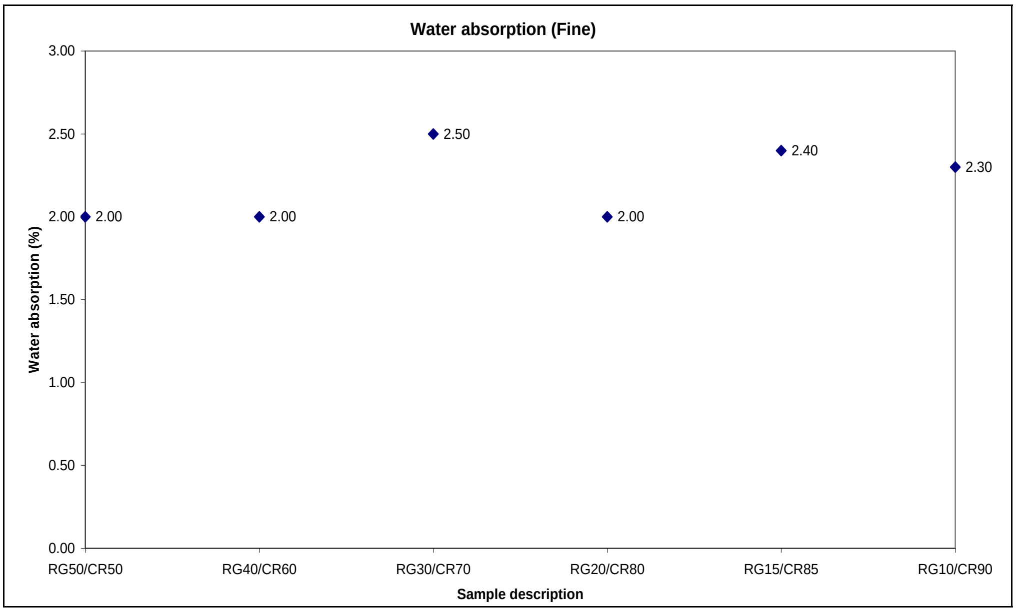

Figure 54: Water absorption (fine) of crushed glass blended with crushed rock (Class 3).

5.2.4 Modified Compaction

The maximum dry densities of blends following compaction range between 2.00 to 2.30 as presented in Figure 55. The optimum moisture contents for blends range between 8.09% to 9.31% as shown in Figure 56.

❖ **Maximum dry density**

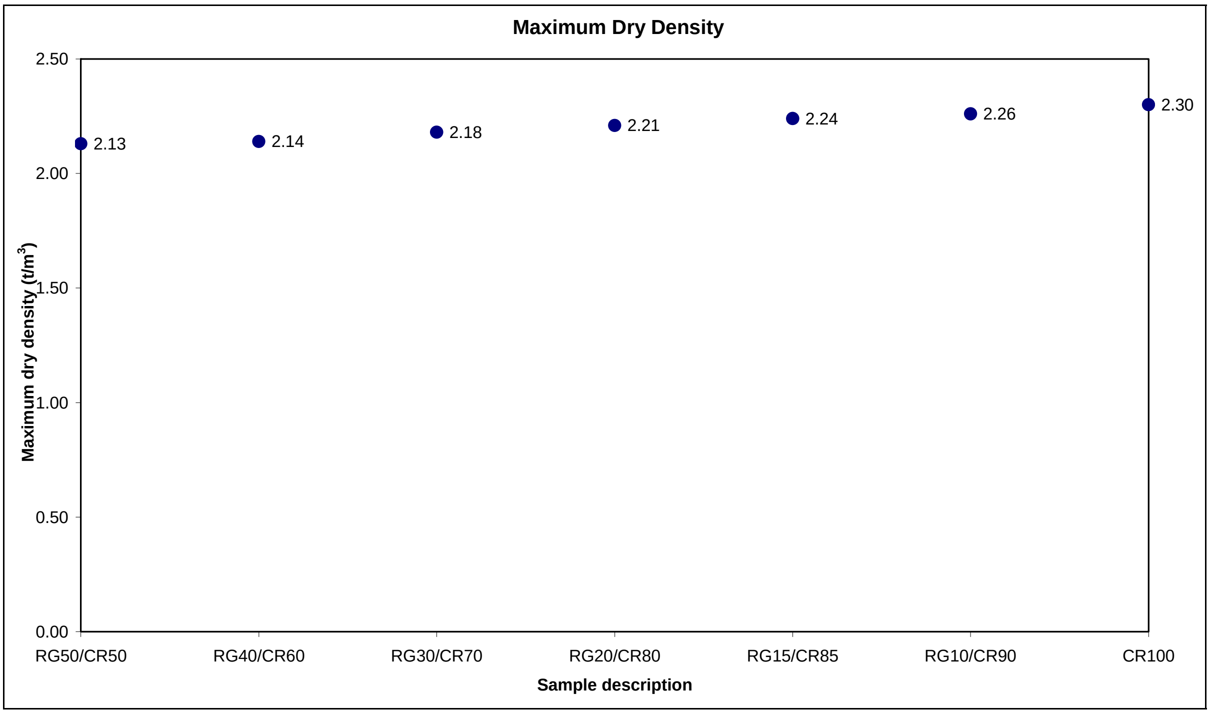

Figure 55: Maximum dry density of crushed glass blended with crushed rock (Class 3)

❖ Optimum moisture content

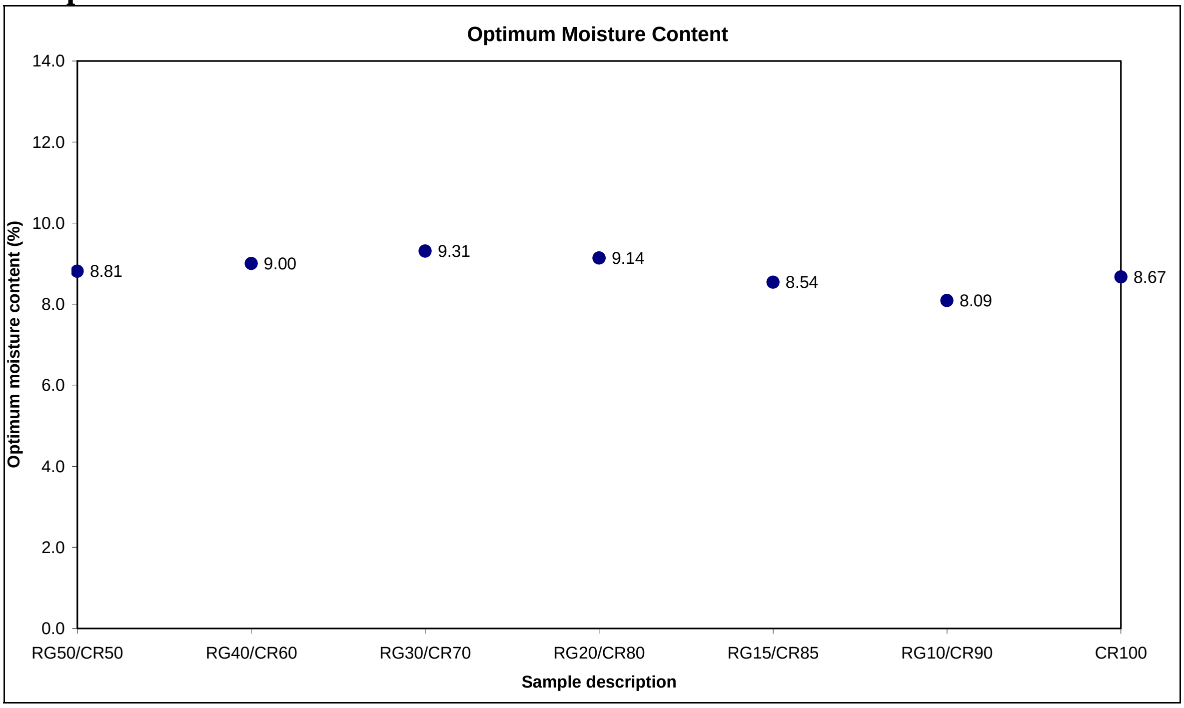

Figure 56: Optimum moisture content of crushed glass blended with crushed rock (Class 3)

5.2.5 California Bearing Ratio (CBR)

The CBR values of all crushed glass and rock blends were above 80%. This satisfies the VicRoads requirement on CBR for crushed rock (Class 3) material. The CBR results of the crushed glass and rock blends are presented in Figure 57.

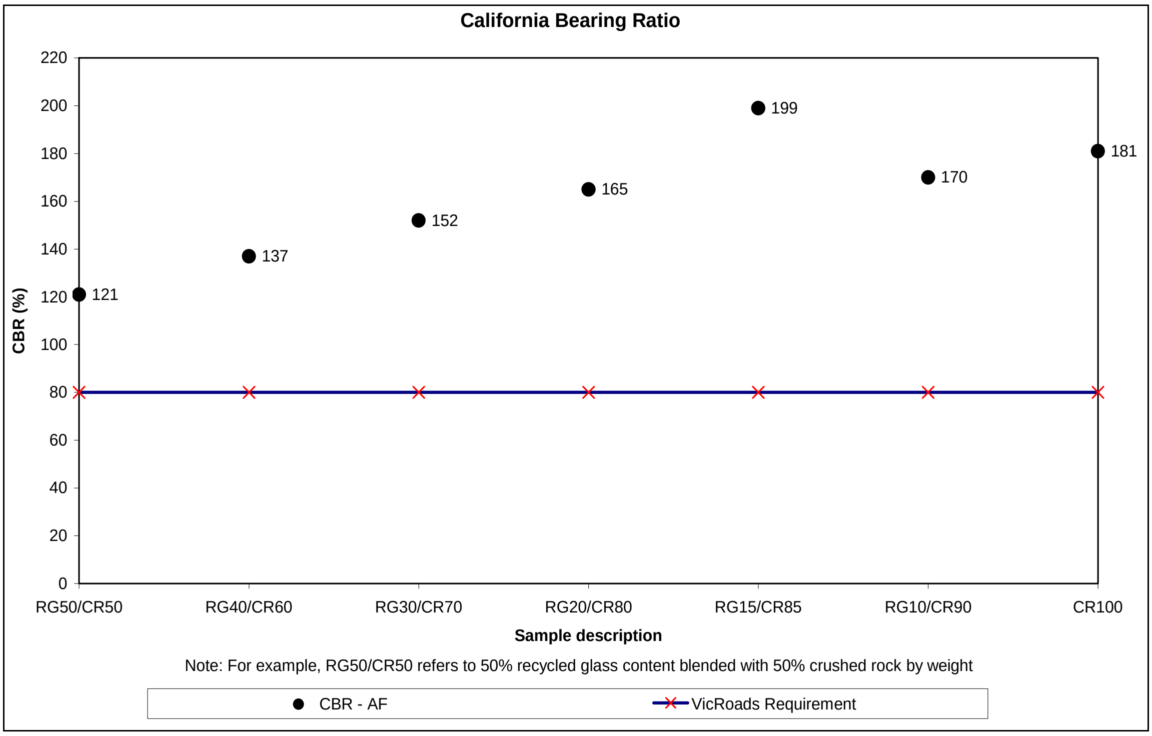

Figure 57: CBR of crushed glass blended with crushed rock (Class 3)

5.2.6 pH

The pH values of all blends range between 9.40 to 9.75. This indicates that the blends are alkaline by nature. The pH results of the blends are presented in Figure 58.

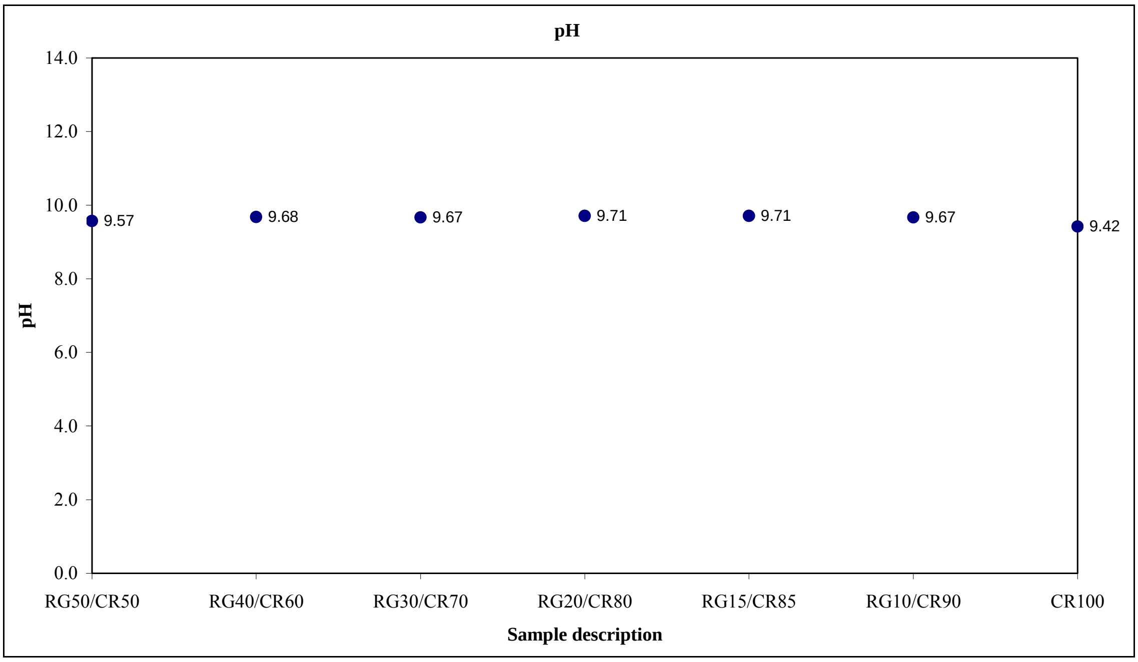

Figure 58: pH of crushed glass blended with crushed rock (Class 3)

5.2.7 Fine Content

The fine content in all blends was less than 11%. The fine content results of the blends are presented in Figure 59.

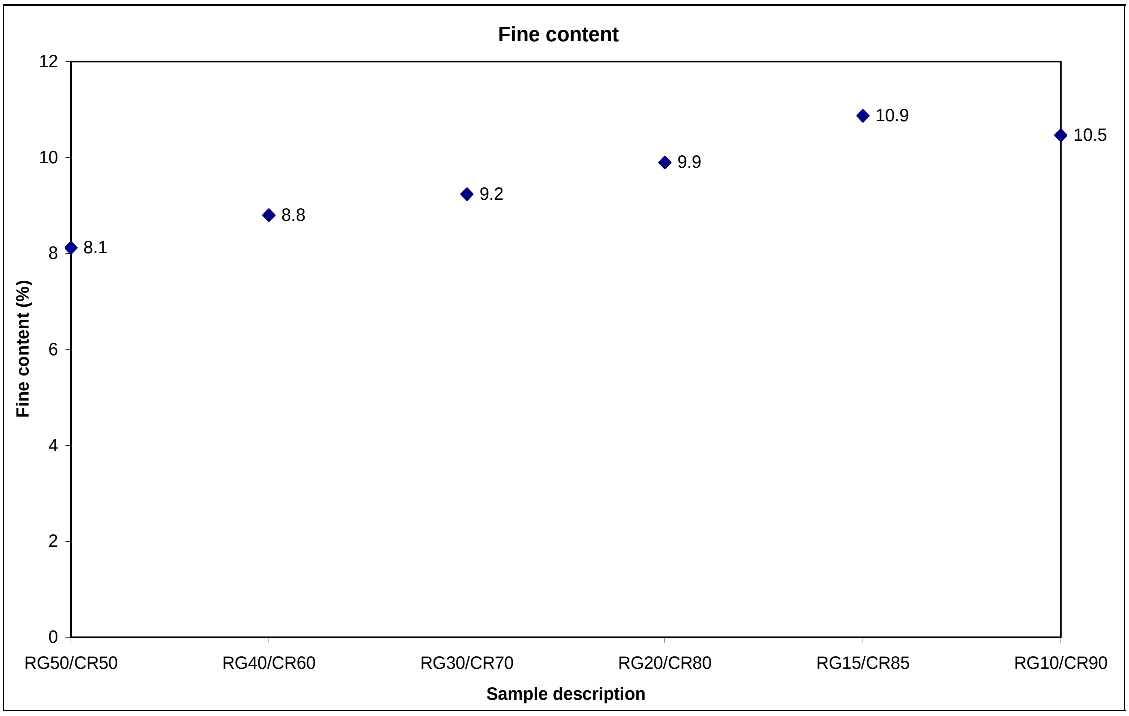

Figure 59: Fine content of crushed glass blended with crushed rock (Class 3)

5.2.8 Plasticity Index

As the clay content in all the blends was low, the plastic limit and liquid limit could not be obtained. This is because the Atterberg limit is directly related to clay mineralogy and as such, higher clay contents result in higher plasticity. This aspect may mean that some difficulties may occur with the workability of the crushed rock blends as cohesion of particles and a "tight" prepared surface is usually a sought after characteristic. A field trial of the crushed concrete would best determine the degree of difficulties that may be experienced.

5.2.9 Organic Content

The organic content of blends are less than 1%. The organic content results of the blends are presented in Figure 60.

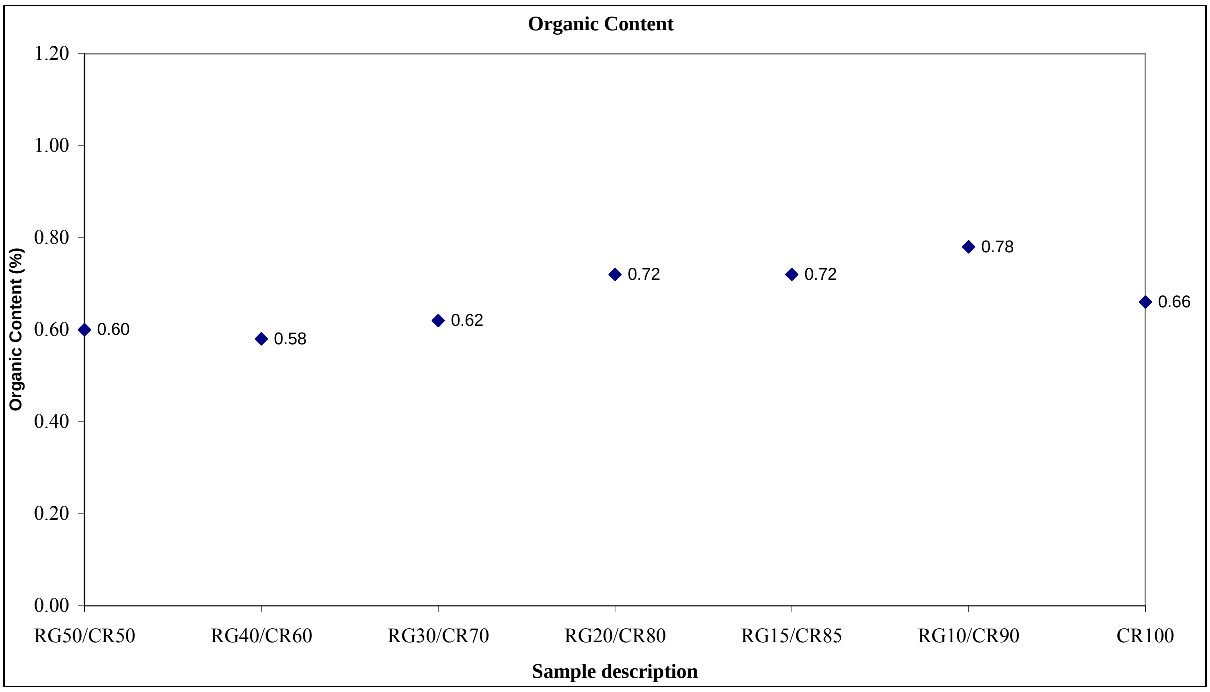

Figure 60: Organic content of crushed glass blended with crushed rock (Class 3)

5.2.10 Los Angeles Abrasion loss

The Los Angeles Abrasion loss values of blends are between 23 to 25. The Los Angeles values of the blends are presented in Figure 61. These values are clearly within the maximum value of 35 normally adopted by VicRoads for Class 3 subbase pavement materials.

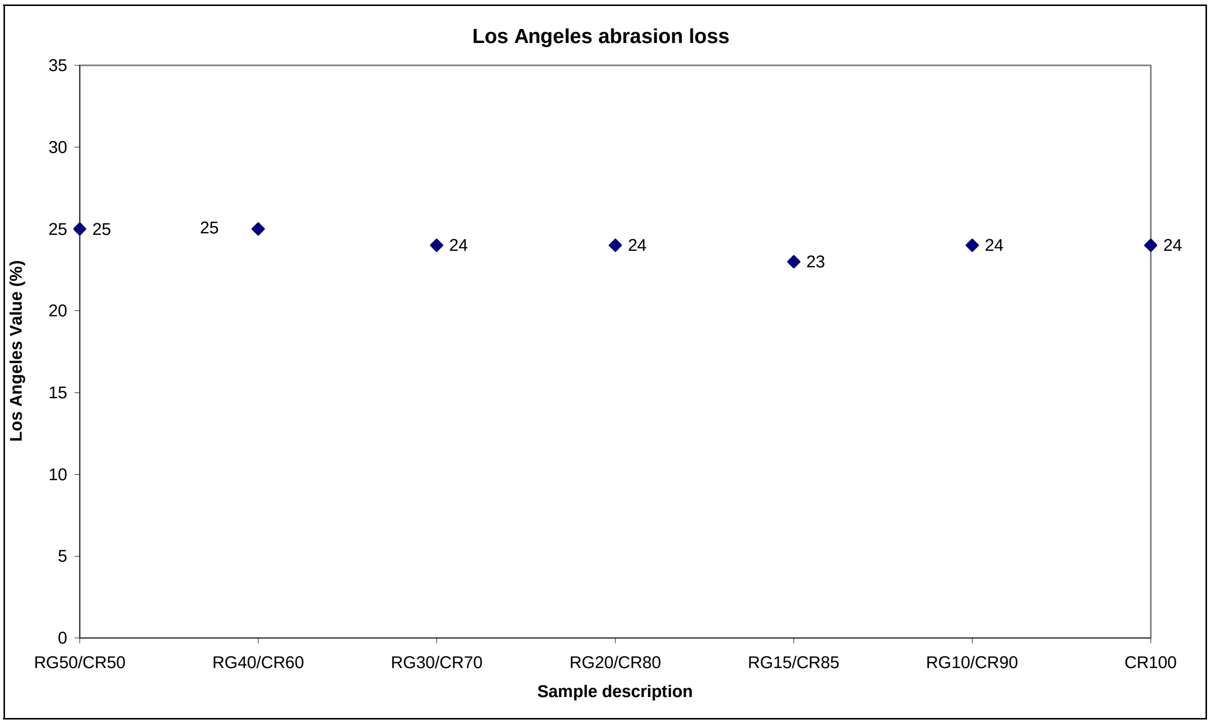

Figure 61: Los Angeles Abrasion loss of crushed glass blended with crushed rock (Class 3)

5.2.11 Permeability

The coefficient of permeability results of the blends is 10^{-7} to 10^{-8}. The coefficient of permeability values of the blends are presented in Figure 62.

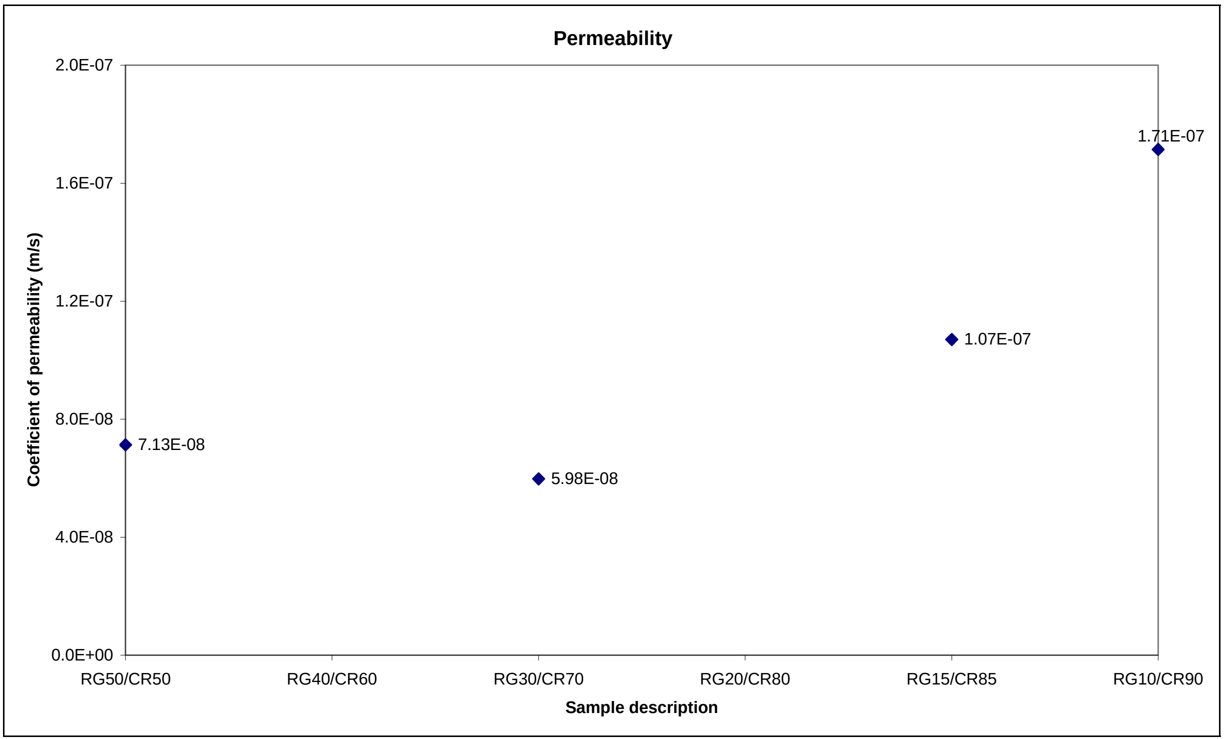

Figure 62: Permeability of crushed glass blended with crushed rock (Class 3).

6 CONCLUSION

The results of the laboratory testing undertaken in this research has shown overall that the incorporation of "crushed brick" and "crushed glass" into basaltic crushed rock or crushed concrete has "low to minimal affect" on the physical and mechanical properties of the original material.

Both the crushed brick and crushed glass blends with crushed concrete and crushed rock are suitable for footpaths and shared paths. The laboratory results indicates that initially up to 50% crushed brick and 30% crushed glass could be safely added to both Class 3 crushed concrete and crushed rock blends for footpath and shared path applications. The crushed glass blends may be increased to 50% depending on the outcome of field trials.

The results of after compaction grading curves for glass blends of 50% and 40% with recycled concrete was noted to be on the VicRoads upper limits. The before and after compaction grading curves for glass blends of 50% with crushed rock was noted to be on the VicRoads upper limits.

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