BEHAVIOR OF CONCRETE WHEN USING RAP (RECLAIMED ASPHALT PAVEMENT) AS A COARSE AGGREGATE MATERIAL

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1 ABSTRACT

The construction industry is one of the fast growing industries in the world and it requires vast amounts resources to be provided to produce the infrastructure needed. As natural resources begin to deplete and are over excavated there becomes a need to find alternative solutions to provide an economical alternative and to remain sustainable.

In the road construction industry asphalt is one of the most commonly used materials as a base and wearing coarse material. When the asphalt pavement reaches the end of its operational lifecycle, this material is removed from the pavement surface by the use of a rotor mill where the material that it produces is processed creating a product called reclaimed asphalt pavement (RAP). Current standards allow for the RAP to be included in the production of hot and warm mix asphalts and as an addition to a manufactured granular base materials.

Concrete is the most widely used product in the construction industry and the environmental and social cost of procuring the required components is quite vast. Aggregate makes up between 60 to 80% of the total mass of the final concrete product and as natural resources begin to diminish and become more expensive to procure there becomes a need to find alternative sources for the fine and coarse aggregates.

The dissertation attempts to determine if RAP could be used in concrete as a coarse aggregate replacement and if so, what is the optimum amount required to produce an economical and durable product to be used.

RAP and virgin 20mm aggregate were used in proportions of 0% RAP/ 100% Virgin aggregate, 20% RAP/ 80% virgin aggregate and then incrementally the RAP percentage was increased by 20% replacing the virgin aggregate until 100% RAP was used in the design mix.

Plastic and hardened state properties of the concrete were undertaken on the samples at the time of batching and 3, 7, 14, 21 and 28 day mark to determine if the inclusion of the RAP into the concrete mix would be affect the properties.

From the results it could be concluded that the inclusion of RAP into the design 25MPa mix would be feasible. The optimum amount to be included would be in a 50:50 ratio, this would allow the concrete to reach its design strength while utilising the available RAP to decrease the amount of virgin aggregates required in the mix.

With further testing the use of RAP in concrete could become another option for the use of recycled aggregates in concrete. As this dissertation was only based on a single 25Mpa design mix this could be expanded to determine if RAP is a viable option for higher strength mixes.

University of Southern Queensland

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2 INTRODUCTION

Concrete is the most widely used product in the construction industry and the environmental and social cost of procuring the required components is quite vast. Aggregate makes up between 60 to 80% of the total mass of the final concrete product and as natural resources begin to diminish and become more expensive to procure there becomes a need to find alternative sources for the fine and coarse aggregates.

For road construction asphalt is predominantly used on most state and federal highways and in areas of high stress. It is the role of the asset maintenance departments to undertake continued assessment on these assets to determine when renewing of the pavement surface is required to prolong the lifecycle of the pavement. The method usually employed at this time is to profile the road surface using a specially designed rotor mill to remove the pavement surface producing a product called reclaimed asphalt pavement (RAP). This product can then be reused in the production of hot mix and warm mix asphalt as well as to produce base and sub-base products to be used in the construction of roads.

2.1 Project Background

Although there are many studies on the use RAP in warm and hot mix asphalt and many studies on the use of crushed concrete as coarse aggregate replacement in asphalt and in road base materials, no studies for the use of RAP as an aggregate replacement in concrete could be located.

Currently RAP is produced and stockpiled in all states of Australia and the world for reuse. Finding an additional use for this material could lead to further cost savings in the production of concrete and as a source of income to owners of assets containing asphalt.

2.2 Research Aims and Objectives

The aim of the project is to ascertain the viability of the use of RAP in concrete and to a base provide technical information on the subject matter that may be expanded on with further studies.

The object of this research project is to determine if the use of RAP in concrete as a coarse aggregate replacement is a feasible option. Tests will be undertaken using RAP from the Roads and Maritime Services stockpile located at Unanderra in New South Wales.

RAP is currently being used in the production of hot mix asphalt (HMA) and warm mix asphalt (WMA) at varying levels across the world and Australia. The testing and analysis of the results will attempt to ascertain what the optimum percentage of RAP will be for the source. As RAP undergoes an oxidation and hardening process the results will only be limited to the RAP tested. Further studies could be undertaken on RAP sources and the results could then be extrapolated to determine optimum amounts given a larger sample and testing size.

Since there are many different tests that can be performed on concrete in its plastic and hardened state, the scope of the project is to focus on the slump (AS1012.3.1), compressive strength (AS1012.9) and Modulus of Elasticity (AS1012.17). The determination of the shrinkage (AS1012.13), creep (AS1012.16) and other concrete properties will be beyond the scope of this project but could be considered in further studies.

2.3 Expected Outcomes

According the current literature where recycled aggregates have been used in the production of concrete, the expected outcomes is that the plastic and hardened state properties will be affected by the inclusion of the RAP. As the bitumen content and level of oxidation of the bitumen will not be measured in this study, it may be inferred that these parameters could have a negative impact on the compressive strength and modulus of elasticity of the hardened concrete as the bitumen enters into a brittle state due to this ageing process.

3 LITERATURE REVIEW

3.1 Asphalt

In the road construction industry, asphalt is one of the most commonly used products as a wearing and base coarse material throughout the world. Asphalt is a mixture of aggregates, binders and common fillers including; fine limestone, stone dust, silica, hydrated lime, ordinary Portland cement and other naturally occurring materials that pass the 75µm sieve (Saffar, 2013). The properties and their interaction within the asphalt matrix can affect the durability of the asphalt when traffic loading is applied to the pavement (Valdés-Vidal, Calabi-Floody, Miró-Recasens, & Norambuena-Contreras, 2015). Therefore the selection of the correct aggregate for an asphalts purpose is important to produce the most suitable mix.

The bitumen used in Australian asphalts is made from heavy crude oil that is imported mainly form the Middle East. It undergoes an extraction process at the oil refineries to produce the various classes of bitumen to be used in the asphalt making process (AAPA, 2014). The bitumen used in asphalting works is affected by temperature, environmental conditions, traffic volume and its resistance to oxidation.

According to the Australian Standard bitumen comes in 7 classes which can be used in different applications. Class 170 is commonly used for sprayed sealing works and used for the production of cold mix and hot mix asphalts for low traffic volume roads. Class 240 is used for sealing and areas with prolonged hot weather. Class 320 is the standard binder used for hot mix asphalts throughout Australia and is used in spray sealing works in very hot areas of the country. Class 450 is used as an asphalt binder in areas that are highly susceptible to rutting and deformations. Class 600 is used where a very structurally stiff asphalt is required e.g. intermediate layers of a heavy duty pavement. Multigrade 500 and Multigrade 1000 is used in asphalts where there is higher than normal deformations and susceptibility to low temperature flexural cracking (AAPA, 2014).

TABLE 2.1

CLASSIFICATION OF BITUMEN FOR PAVEMENTS

Formal grade designation	Informal designation	Primary specified property—Viscosity at 60°C Pa·s	
		Pre-RTFO treatment	Post-RTFO treatment
Class 170	C170	140 to 200	—
Class 240	C240	190 to 280	—
Class 320	C320	260 to 380	—
Class 450	C450	—	750 to 1150
Class 600	C600	500 to 700	—
Multigrade 500	M500	400 to 600	—
Multigrade 1000	M1000	—	3500 to 6500

NOTE: Post-RTFO treatment values shown in Table 2.1 correspond to those specified when RTFO treatments are performed using AS/NZS 2341.10.

Figure 1: Bitumen classifications AS2008 (Limited, 2013)

Hot mix asphalt is a premium road building material and it is important that the right asphalt is selected for its intended purpose. The asphalt is transported from the batching plant to the site at around 170ºC and should be placed and fully compacted before the temperature cools to around 90 ºC. Compaction of the asphalt mat should be uniform and the proper equipment should be used to provide a complying product. Once this has taken place the asphalt mat will form an abrasion resistant surface to be trafficked.

Asphalt can be used as the wearing course and as a structural treatment in the pavement. Structural treatments include the intermediate and base course and these mixes are generally dense grade mixes and using a nominal 20mm aggregate but can sometimes be a 40mm mix. These structural treatments generally use a Class 320 or Class 600 bitumen for a superior strength and stiffness.

Asphalt Description	Nominal Size (mm)	Binder Class	Application
Medium duty base and intermediate course	20	320	Roads with 500 to 10,000 vehicles per lane per day.
Heavy duty intermediate course (high stiffness)	20	600	Freeways and heavy freight routes with > 10,000 vehicles per lane per day.
High performance intermediate (enhanced resistance to deformation and flexural fatigue).	14 & 20	PMB (A10E and A15E)	For rehabilitation of medium and heavy duty pavements prone to flexural cracking and deformation particularly at heavily trafficked signalized intersections and roundabouts.
Heavy duty base	20 (28 & 40 rarely used)	320	High bitumen content layer (0.5% to 1% higher than normal for high flexural fatigue resistance).

Figure 2: Typical intermediate and base course mixes (AAPA, 2014)

Asphalt used as a wearing courses should have the following properties;

- Resistance to deformation
- Resistance to abrasion
- Skid resistance
- Resistance to fatigue
- Low permeability unless it is specified as an open grade.

The common wearing type asphalts used in Australia are Dense Grade Asphalt (DGA), Stone Mastic Asphalt (SMA), Open Grade Asphalt (OGA) and Fine Gap Graded Asphalt (FGGA).

DGA is made up of well graded aggregate and different binder types depending on its application. DGA can be used in various locations and will suit all traffic volumes.

SMA is made of a coarse graded aggregate and is bound with a filler mastic. It is usually comes as a 7, 10 or 14mm stone. It is considered to be a higher quality wearing coarse product in comparison to DGA as it has a higher content of aggregate, higher binder content and low air voids which provides improved resistance to deformation, greater surface texture and a more durable product.

OGA is specifically designed with a higher air void content (20-25%) and more binder content (5-6%). OGA is typically used in urban freeways due to it lower traffic noise. The higher air voids also allows for grater surface drainage which leads to a decrease in traffic water spray.

FGGA is commonly used in light duty applications where there is low traffic volumes and less susceptibility to high stresses.

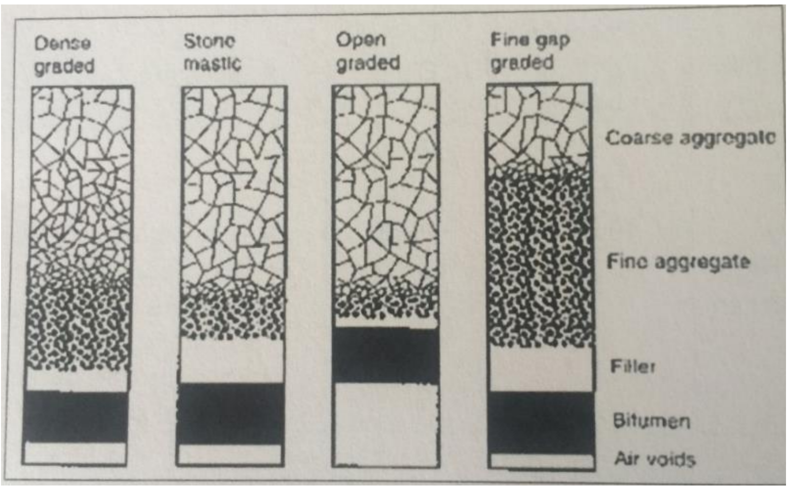


Figure 3: Typical asphalt mixes (AAPA, 2014)

The interaction with the bitumen binder and the aggregates will affect the performance of the asphalt when under stress. The two main groups for analysing the effect of the binder aggregate interaction are; evaluating the properties related to thermodynamics and the mechanical methods (Guo, Motamed, Tan, & Bhasin, 2016).

The morphological properties of an aggregate used in the production of asphalt can influence the mechanical properties of the product. Valdés-Vidal et al (2015) stated that the morphology and the asphalts aggregate grading's will affect the overall mechanical properties of the asphalt. The origin, type, size, surface texture and angularity of the aggregate will affect the mechanical properties of the asphalt mix.

The grading of the selected aggregate will affect the internal friction and therefore the performance of the asphalt pavement. The morphology of the selected coarse aggregate can affect its susceptibility to rutting, fatigue cracking and the asphalts resistance to traffic loadings (Valdés-Vidal et al., 2015).

3.2 Reclaimed Asphalt Pavement (RAP)

3.2.1 Using RAP in Asphalt

Reclaimed asphalt pavement is the product made during the milling and processing of existing asphalt pavements. Across Australia and the world in the road infrastructure industry this material is currently being reused in the production of hot mix asphalt (HMA) and warm mix asphalt (WMA) as a means to preserving natural resources and limiting the need to send the product to landfill sites (Miliutenko, Björklund, & Carlsson, 2013).

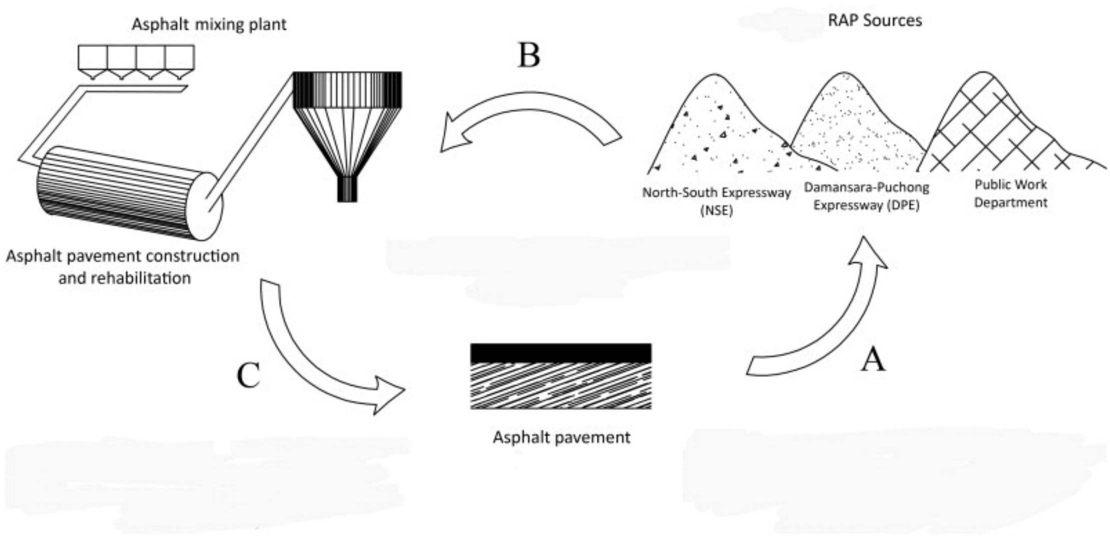


Figure 4: Schematic lifecycle of asphalt pavements (Jamshidi, Hamzah, & Shahadan, 2012)

There has been a significant amount of research undertaken all around the world into the use of RAP in pavement technology but limited amount of the use of RAP in concrete. During the pavements normal lifecycle the binder content will undergo an ageing process and deterioration that will continue even after the pavement has been milled and processed (De Lira, Cortes, & Pasten, 2015).

Asphalt oxidisation changes the properties of the binder and has ben hypothesized to be a main contributor of ongoing pavement failures. An extensive amount of research has been done on the effects of binder oxidation and that the process makes the binder stiffer and more brittle which leads to higher binder stresses and therefore pavement deformation and failures (Jung, 2006).

Jung (2006) found that when tests were taken on 15 different pavements within the Texas road network unmodified binders will typically harden and become more brittle than has been generally hypothesized in comparison to laboratory testing.

A study undertaken by De Lira, Cortes and Pasten (2015) found that after processing of the RAP occurs, the amount of continued oxidation is directly related to the particle size and that stockpiling of larger sized particles will reduce the amount oxidisation and extend the products shelf life (De Lira et al., 2015).

Pavements that have been previously placed and overlayed with asphalt containing RAP have been found to have a shorter pavement life than those without incorporated RAP. This could be attributed to the amount of oxidation and break down of the binder content (Yang & Lee, 2016) which will continue even after milling.

In Australia each state has their own specifications which dictates the allowable amount of RAP to be used in either the HMA or WMA. This amount can differ depending on which layer of the pavement the asphalt will be located in.

Roads and Maritime Services (RMS) of New South Wales specification R116 Heavy Duty Dense Grade Asphalt states that

> *"You are permitted to use RAP material in the wearing and other courses up to a maximum of 15% (by mass)"*

((RMS), 2012)

Queensland's Transport and Main Roads Technical Specification MRTS30 Asphalt Pavements also states that

"RAP material: binder content and grading. Where the Contractor proposes to include more than 15% RAP in the mix, the viscosity of the recovered RAP binder shall also be provided"

((TMR), 2016)

Main Roads Western Australia Specification 504 Asphalt Wearing Course states that

"RAP shall not be included in the production of any asphalt wearing course"

(MRWA, 2016a)

Although in the pavement intermediate course it allows

"Up to 10% of RAP by mass of the total aggregate may be used in the production of 14mm or 20mm asphalt"

(MRWA, 2016b)

As can be seen from the different specifications of three Australian states, each authority has their own interpretation on the use of RAP in their asphalt mixes and the level within the pavement that it can be used.

There is also a push in the use of RAP in asphalt as a means of decreasing the environmental impact associated with the production of asphalt. Many studies have been undertaken to determine the whole of life cycle assessment in production.

Manufacturing of HMA occurs between 150º and 190º C whereas WMA occurs between 100º and 140º C. The lowering of the temperature in the production of asphalt provides an immediate offset in the environmental impacts associated with production. Therefore lowering the temperature to produce WMA and the addition of RAP to the mix will have an immediate effect.

This lowering of the temperature is achievable now due to advances in technology and changes to the production methodologies. Patented products and water-based foaming technologies allow the binder to be produced at a lower temperature and mixed with the aggregates to produce asphalt (Vidal, Moliner, Martínez, & Rubio, 2013).

3.2.2 RAP as a Base Material

The general cross section of a road will consist of surfacing, base, sub-base, select material and the subgrade. In the construction of new roads and maintenance activities undertaken on existing roads there is a requirement to provide the appropriate quality products to ensure that the pavement will stand up to the traffic loadings that it has been designed for.

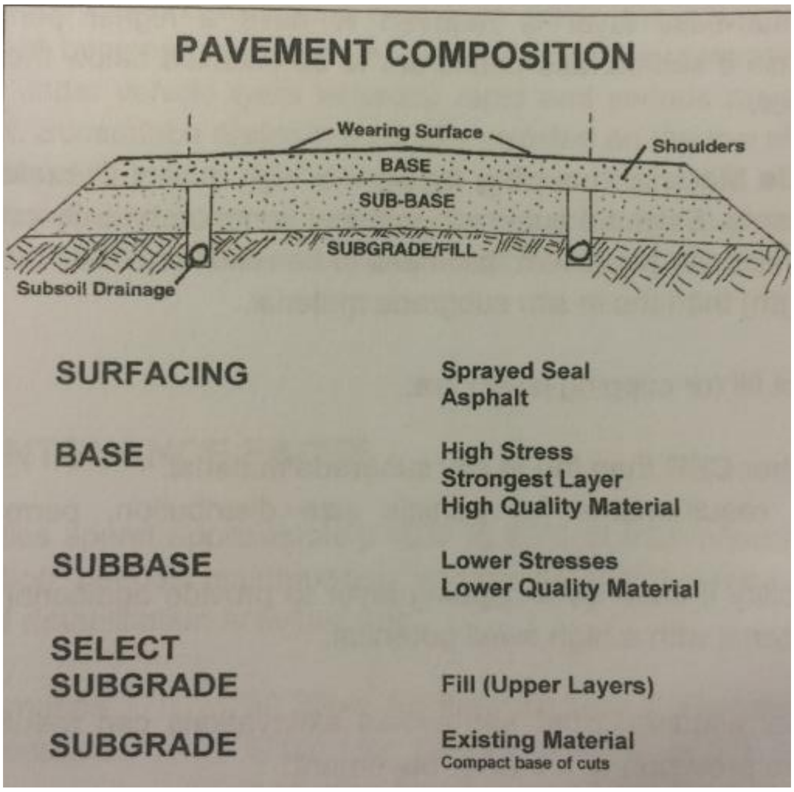


Figure 5: Typical Pavement Cross Section (AAPA, 2014)

In New South Wales, the road authority Roads and Maritime Services (RMS) allows for the use of cold milled RAP to be used in the production of base and sub-base materials. Recycled materials may be used in conjunction with either virgin or blends of other recycled materials to produce a conforming product once tests have been undertaken and results submitted to the verifying principal for review. RMS also specify the maximum allowable amount of undesirable material in the production of their base and sub-base materials.

Material	Unbound or Modified Base and Subbase	Bound Base and Subbase
Iron and Steel Slag	100%	100%
Crushed Concrete (i)	100%	100%
Crushed Brick (ii)	20%	10%
RAP (iii)	40%	40%
Fly Ash (iv)	10%	10%
Furnace Bottom Ash (iv)	10%	10%
Crushed Glass Fines (v)	10%	10%

Figure 6: RMS' allowable recycled materials for base and sub-base applications ((RMS), 2014)

Undesirable Constituent Material Type	Traffic Category	Maximum Limit by Mass of each Constituent Material (Test Method RMS T276)	
		Base	Subbase
Metal, Unprocessed Glass, and Ceramics (excluding bricks)	A	1%	2%
	B	1%	2%
	C and D	2%	3%
Plaster, Clay Lumps and Other Friable Material	A	0.1%	0.5%
	B	0.2%	0.5%
	C and D	0.5%	0.5%
Rubber, Plastic, Paper, Cloth, Paint, Wood and Other Vegetable Matter	A	0.1%	0.2%
	B	0.1%	0.2%
	C and D	0.2%	0.2%
Free lime content [i]	All	0.6%	0.6%
Tar (including coal tar)	All	0%	0%

Figure 7: Maximum allowable amount of undesirable material ((RMS), 2014)

RMS' Specification for granular base and sub-base materials divides the requirements into four different traffic categories; Traffic Category A, B, C and D with A having the highest requirements for material properties.

Applicable Traffic Category:	**A / B / C / D**

Table 3051/A.1 - Relationship Between Design Traffic and Traffic Category

Design Traffic, N (DESA) [1, 2]	**Traffic Classification**	**Traffic Category** [3]
$N \geq 10^7$	Very heavy	A
$10^7 > N \geq 4 \times 10^6$	Heavy	B
$4 \times 10^6 > N \geq 10^6$	Medium	C
$N < 10^6$	Light	D

Notes:

(1) DESA: Design Equivalent Standard Axle loading

(2) Based on 20 year design life for design lane

(3) Category specified is the lowest acceptable, but may be substituted by materials suitable for higher Design Traffic loading.

Figure 8: RMS' traffic categories ((RMS), 2014)

The base material is usually comprising of a higher quality material that is able to be compacted to a high density and which will provide resistance to rutting under design traffic loadings, a controlled particle size distribution which will produce a dense pavement layer and provide a high resistance to sprayed bituminous products, made up of sound and durable rock particles that will not break down under the loadings of construction vehicles during construction and traffic loadings (AAPA, 2014).

The sub-base is made up of lower quality materials with less focus on particle size distribution and plasticity limits they are usually also cheaper to produce.

Particle size distribution (grading's) and plasticity index (PI) form an important part in the selection of suitable materials to be used in the production of base and sub-base materials for the construction of roads.

A well graded material when compacted will have a higher density, lower permeability and a higher strength whereas a poorly graded material will not have the required properties. When a material that has a high PI this is generally an indication that the material has a high clay content which is not desirable in a base and sub-base material. This high clay content can lead to early deformations in the pavement when opened to traffic and will cause problems for the construction crew during construction. Having no PI at all in a product will cause problems as the product will have low cohesion properties and can be difficult to compact (AAPA, 2014). RMS' specification for dense graded bases have tight controls on both the grading's and PI limits when constructing pavements.

Property	Unbound Material/Material To Be Modified				Material To Be Bound	
	DGB20(HD)	DGB20	DGS20	DGS40	MB20	MB40
	Base		Subbase		Base/Subbase	
RMS T109: Plasticity Index (PI) (i)						
- For Traffic Category A	max 6 min 2 (ii)	–	max 6	max 6	max 2	max 2
- For Traffic Category B and C (iv)	–	max 6 (iv) min 2 (ii)	max 10	max 10	max 6	max 6
- For Traffic Category D (iv)	–	max 8 (iv)	max 12	max 12	max 10	max 10
RMS T108: (i)						
Liquid Limit (if material non-plastic)						
For natural or manufactured materials						
- For Traffic Categories A	max 20 (v)	–	max 23	max 23	–	–
- For Traffic Categories B, C and D	–	max 23	max 23	max 23	–	–
For recycled material	max 27	max 27	max 27	max 27	–	–
RMS T109: (i)						
Plastic Limit (if plastic)	max 20	max 20	max 20	max 20	–	–
AS 1289.6.7.2 (i)						
Permeability (m/sec)						
- For Traffic Category A (iii)	max 5×10^{-8}	–	–	–	–	–

Figure 9: RMS' PI limits for densely graded base materials ((RMS), 2014)

Property	Unbound Materials/Material To Be Modified				Materials To Be Bound	
	DGB20(HD) (ii), (iii)	DGB20 (ii), (iv)	DGS20 (ii)	DGS40 (ii)	MB20 (v)	MB40 (v)
	Base		Subbase		Base/Subbase	
RMS T106 and RMS T107, AS 1289.3.6.1 (v): Particle Size Distribution (i) Passing AS Sieve (% by mass)						
75.0 mm	–	–	–	–	–	–
53.0 mm	–	–	–	100	–	100
37.5 mm	–	–	–	95 – 100	–	–
26.5 mm	100	100	100	75 – 95	100	–
19.0 mm	95 – 100	95 – 100	95 – 100	64 – 90	95 – 100	55 – 80
13.2 mm	78 – 92	78 – 92	70 – 90	–	70 – 90	–
9.5 mm	63 – 83	63 – 83	58 – 80	42 – 78	60 – 80	30 – 55
4.75 mm	44 – 64	44 – 64	43 – 65	27 – 64	–	–
2.36 mm	33 – 49	33 – 49	30 – 55	20 – 50	30 – 50 (vi)	20 – 40
425 µm	14 – 23	14 – 23	10 – 30	10 – 23	10 – 25 (vi)	8 – 25
75 µm	7 – 14	7 – 14	4 – 17	4 – 12	4 – 12 (vi)	3 – 10
13.5 µm (vii)	3 – 7	3 – 7	2 – 10	2 – 7	–	–
Retained between AS Sieves (% by mass)						
37.5 mm						
	–	–	–	–	–	–
26.5 mm						
	–	–	–	–	–	–
19.0 mm						
	7 – 17	6 – 18	–	–	–	–
13.2 mm						
	8 – 16	7 – 17	–	–	–	–
9.5 mm						
	14 – 24	13 – 25	–	–	–	–
4.75 mm						
	8 – 18	7 – 19	–	–	–	–
2.36 mm						
	14 – 28	14 – 30	–	–	–	–
425 µm						
	6 – 13	6 – 13	–	–	–	–
75 µm						
	3 – 7 (vii)	3 – 8 (vii)	–	–	–	–
13.5 µm						

Figure 10: RMS' material grading's for densely graded base materials ((RMS), 2014)

3.3 Concrete

With the increasing push towards green technologies and sustainable practices, the civil construction and building industry have invested large amounts of time and resources into meeting these needs.

Concrete is one of the most widely used materials in the industry. Applications of concrete can be found in roads, bridges dams, towers and building to name a few. Albeit this also comes with the carbon footprint associated with the production and use of the product.

Crow (2008) concluded that concrete production is responsible for up to 5% of the annual anthropogenic Carbon Dioxide (CO_2) with China's booming construction industry being responsible for around 3% of that figure. CO_2 is the main greenhouse gas produced by the chemical reaction that happens in the production of concrete (Mitchell Crow, 2008).

Concrete has been produced for thousands of years with the basic components of the mixture being relatively unchanged of sand (fine aggregate), gravel (coarse aggregate), cement (pozzolanic material) and water. In 2008 nearly 2 billion tonnes of concrete was produced and is set to reach nearly four times that amount by 2050.

Concrete is used on such a large scale due to its workability in its plastic state and its hardened properties and in comparison to steel is financially more expensive but with less environmental impact (Mitchell Crow, 2008).

With the natural depletion and over excavation of virgin materials used in the production of concrete, industry have attempted to recycle and source sustainable materials including fine and course aggregates as well as materials that have a pozzolanic reaction.

3.3.1 Recycled Aggregates

The global requirements for building materials is set to increase as more developments begin every year. As this happens construction and demolition waste increase, of this waste a majority has the potential to be recycled and re-used in the construction of new infrastructure.

In 2006-07 Australia produced more than 43.8 million tonnes of waste of which 29% was form households, 33% form the industrial sector and 38% from the construction and demolition sector (Statistics, 2013).

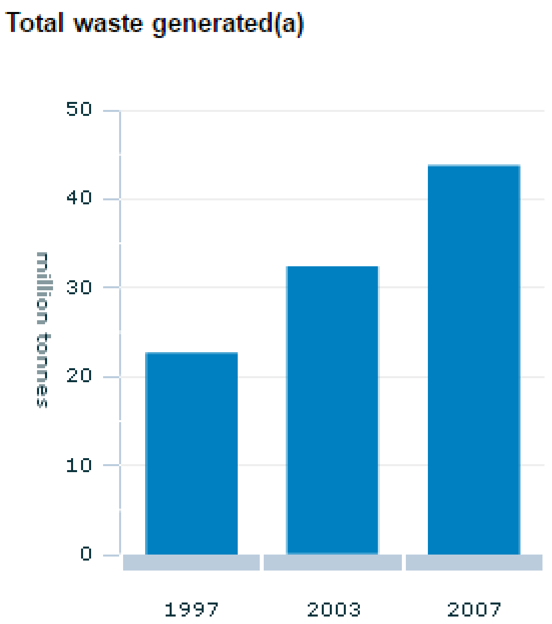


Figure 11: Total Waste Generated in Australia (Statistics, 2013)

Aggregates form up to 60-80% of the total mass of concrete and a high proportion of the construction waste generated has the potential to be recycled and used as an aggregate substitute. Aggregates in the production of concrete can then also be broken down into its fine and coarse components.

The amount of water required and to achieve the desired workability of a concrete mix is highly dependent on the quantity and the properties of the fine aggregates in the concrete mix designed (Singh, Nagar, & Agrawal, 2016).

When replacing fine aggregates in a mix, the physical and chemical properties of the replacement will have an effect on the plastic and hardened state properties. Therefore testing should be undertaken to ensure that the aggregate still meets the mechanical and durability requirements for the mix design (Tiwari, Singh, & Nagar, 2016).

A thorough investigation should take place before incorporating any fine aggregate into a concrete batch to fully determine its properties this can be determined by the flow chart as seen in Figure 12.

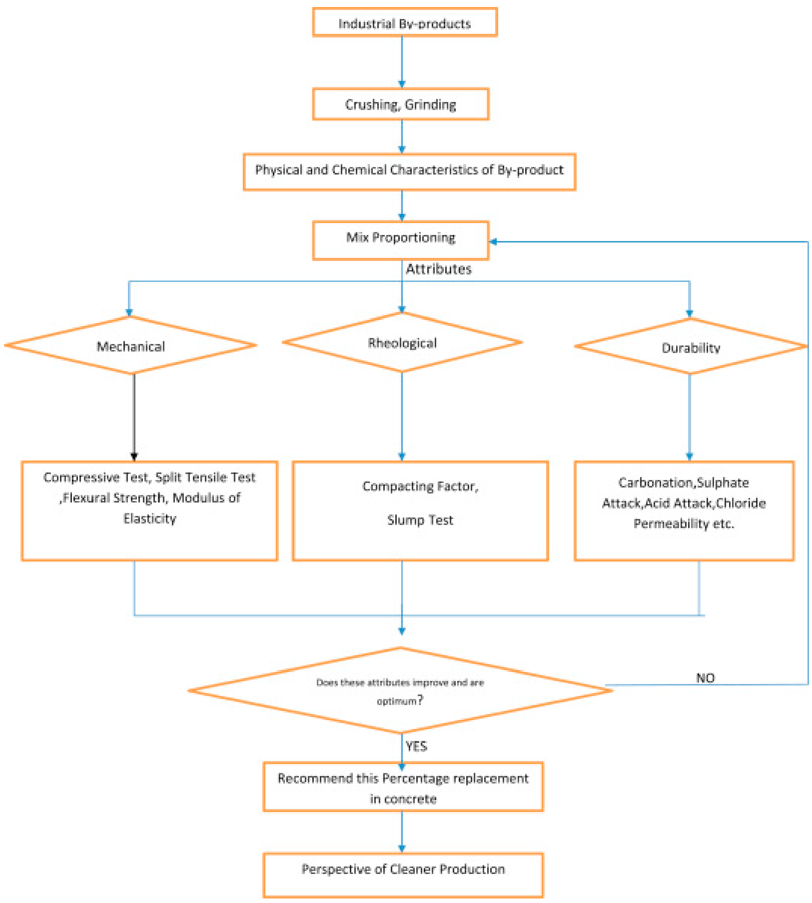


Fig. 2.
Flow chart explaining the present methodology for potential inclusion of industrial byproducts as partial replacement of sand in concrete-Stage I.

Figure 12: Flow Chart to Determine Aggregate Properties (Tiwari et al., 2016)

When utilising a new recycled product as an aggregate substitute, the properties of the aggregate need to be tested to see how they perform under different conditions. Determining the proper grading and shape will affect the workability of the plastic concrete and having an aggregate with poor strength and durability properties will affect the hardened state properties of the concrete.

3.4 Testing and Properties of Aggregates

The properties of the aggregate to be used when designing a mix should be known to obtain the best outcome. These include;

- Shape
- Texture
- Size
- Angularity

- Moisture content
- Bulk density
- Specific gravity
- Reactivity
- Soundness.

These properties will affect the strength, workability and durability of the mix design (http://www.engr.psu.edu/, 2016). For the purposes of this research the samples were obtained from the stockpiles in accordance with AS1141.3.1 – Method 8.4.3.

3.4.1 AS1141.11.1 Methods for Testing and Sampling Aggregates – Sieving Method

- Apparatus
  - Balances
  - Drying oven complying with AS1141.2
  - Sample divider
  - Sieves
  - Brush
  - Sieve shaker
- Test portions per Figure 13

TABLE 1

MINIMUM MASS OF TEST PORTION FOR SIEVING

Nominal size mm	75	40	28	20	14	10	7	5	Fine aggregate	Fillers
Graded aggregate	30 kg	15 kg	5 kg	3 kg	1.5 kg	800 g	500 g	300 g	150 g	25 g
One-sized aggregate	25 kg	10 kg	4 kg	1.5 kg	700 g	500 g	300 g	200 g	100 g	–

Figure 13: Minimum Mass for Test Portion (Limited, 2009)

- Procedure
  - Nest the sieves in order from largest to smallest, placing the sample in the top sieve
  - Agitate the sieves by hand or mechanical means
  - Determine the mass of sample retained on each sieve size (Limited, 2009).

3.5 Aggregate Size Distribution

Aggregate forms up to 60-80% of the concrete matrix, therefore it is important to understand the properties of the aggregate to be used. The size of the aggregate that is to be used for the mix design will affect the plastic and hardened properties of the concrete. Using a larger aggregate size in the concrete mix will usually reduce the cost of the final product as it may decrease the amount of cement required (ConcreteNetwork.com, 2016). Sieving of the aggregate samples were completed in accordance with AS1141.11.1.

As can be seen from Figure 15-17, the 10 and 20mm virgin aggregate, 20mm RAP did not fall wholly within the allowable range for an aggregate to be used in concrete production in accordance with AS2758.1: 2014 Aggregate and Rock for Engineering Purposes – Concrete Aggregates. The sand sample seen in Figure 18 does fall within the allowable limits for a concrete aggregate.

Ingredient	Range
Cement	7% - 15%
Aggregate	60% - 80%
Water	14% - 18%
Air	2% - 8%

Figure 14: Proportions of Concrete Mixture (ConcreteNetwork.com, 2016)

Table 1: 10mm Aggregate Sieve Analysis

Sieve size (mm)	19	13.2	9.5	6.7	4.75	2.36	1.18	0.06
Percent passing	100	100	93	54	19	5.0	3.0	2.5

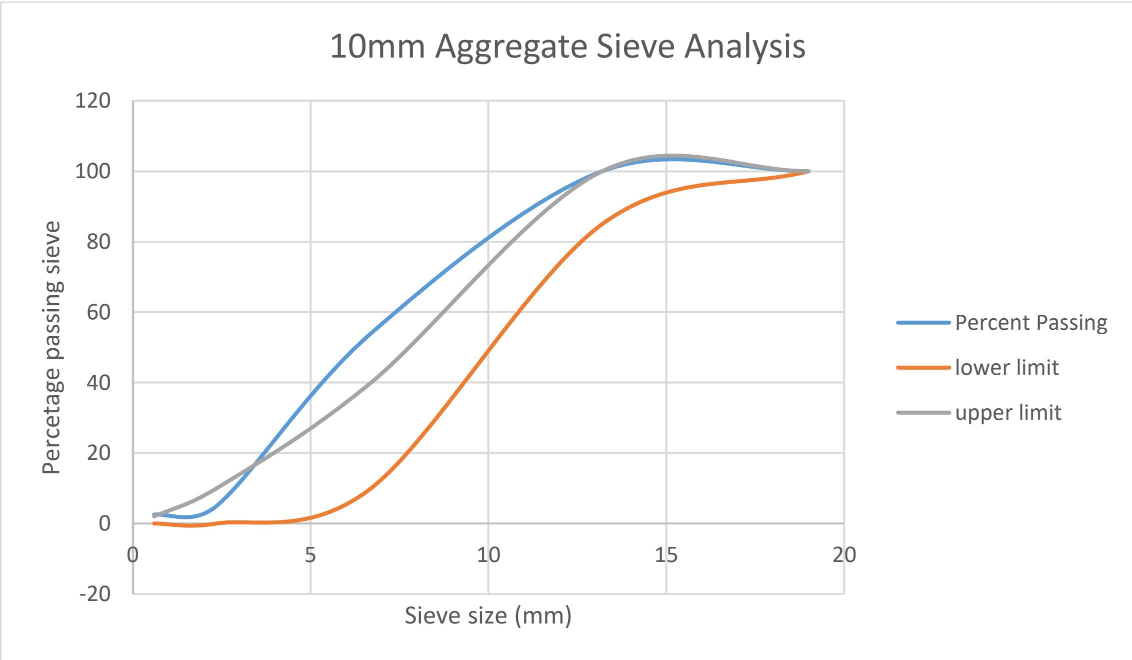


Figure 15: 10mm Aggregate Sieve Analysis

Table 2: 20mm Aggregate Sieve Analysis

Sieve size (mm)	26.5	19	13.2	9.5	6.7	4.75	2.36	1.18	0.06
Percent passing	100	95	63	18	7.0	4.0	3.0	3.0	2.5

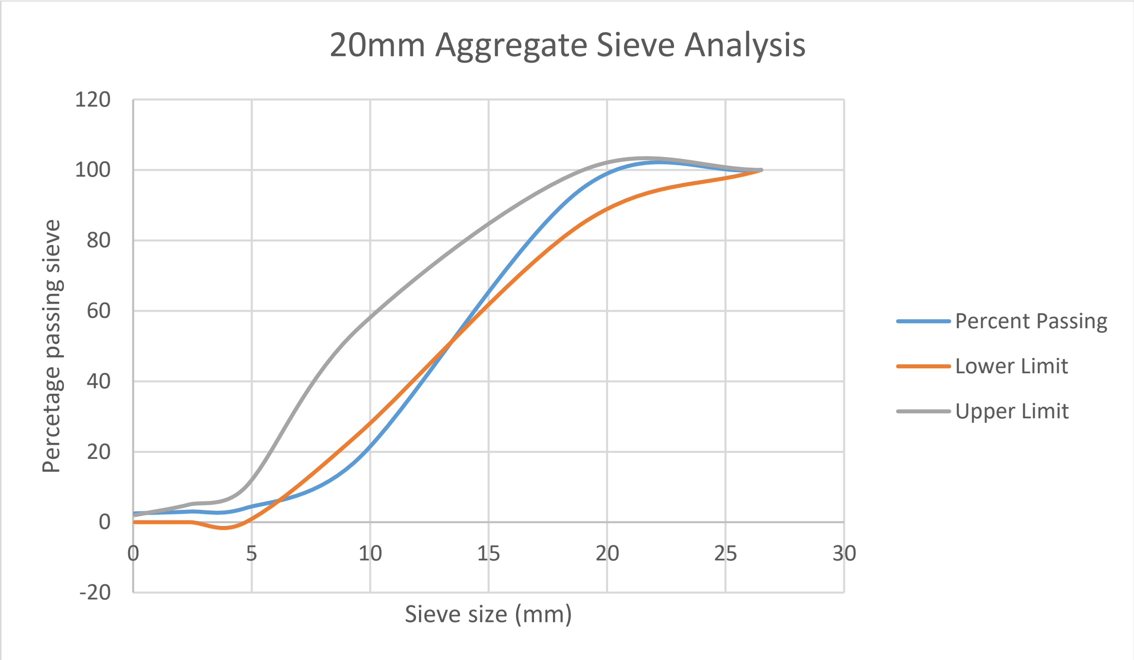


Figure 16: 20mm Aggregate Sieve Analysis

Table 3: 20mm RAP Sieve Analysis

Sieve size (mm)	26.5	19	13.2	9.5	6.7	4.75	2.36	1.18	0.06
Percent passing	100	53	3	0.5	0.5	0	0	0	0

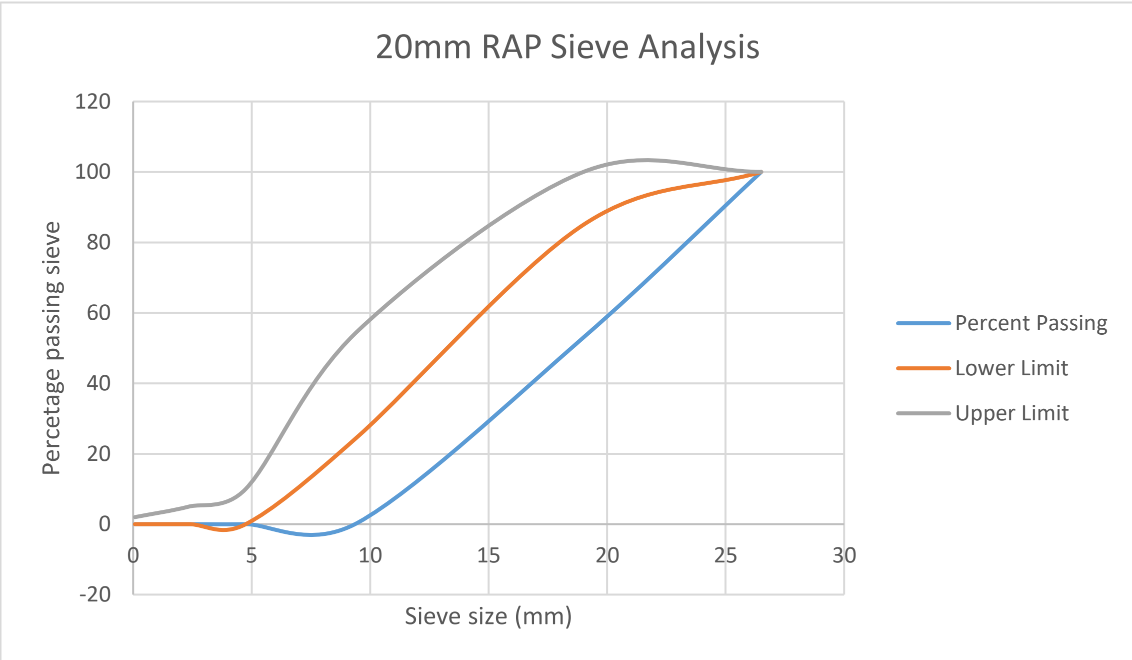


Figure 17: 20mm RAP Sieve Analysis

Table 4: Fine Aggregate (Sand) Sieve Analysis

Sieve size (mm)	4.75	2.36	1.18	0.06	0.0425	0.03	0.015	0.0075
Percent passing	100	93	82	64	48.7	32.5	7.5	2.5

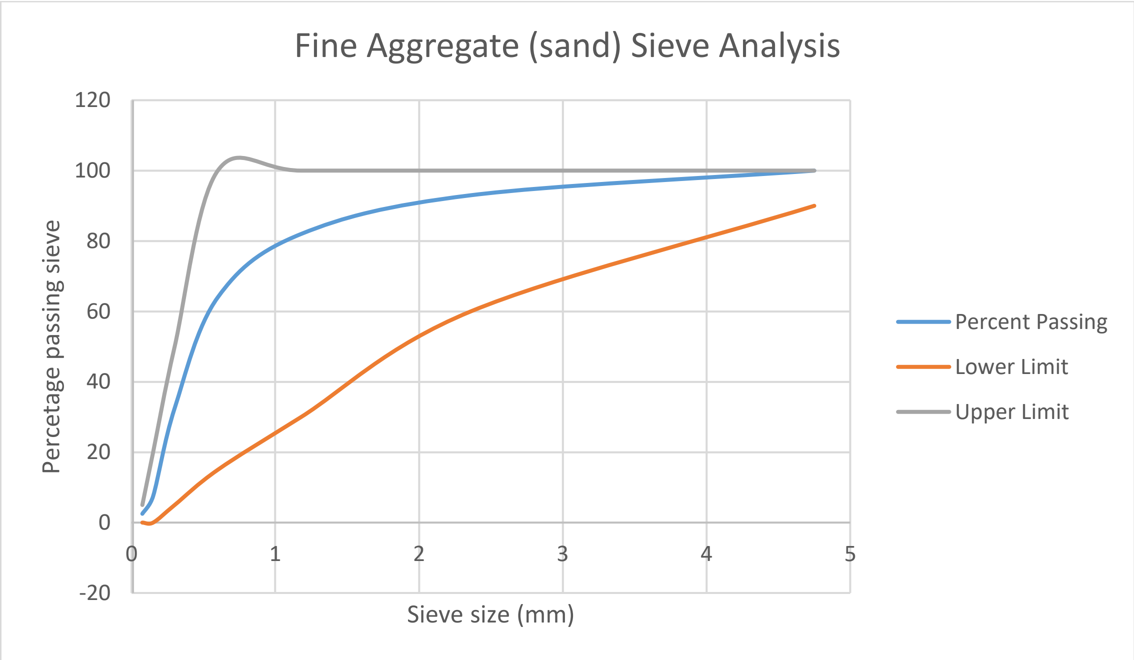


Figure 18: Fine Aggregate (Sand) Sieve Analysis

3.6 Literature Review Conclusion

It has been identified that based on the study of the current literature, there is a very limited amount of research that has taken place on the use of RAP in concrete mixes. The Florida Department of Transport undertook a study in 2012 that utilised the use of RAP in concrete pavement slabs. Like this research project the study looked to use varying amounts of RAP as an aggregate replacement in concrete. They were able to do far more testing on the concrete that was produced allowing them to have a far larger selection of results to draw their conclusions from.

This research undertaken in this dissertation and the research formally done by the Florida Department of Transport could provide a platform for more research to be undertaken and potentially fill the knowledge gap that currently exists.

4 METHODOLOGY

4.1 Introduction

There are usually three major factors when selection of the appropriate mix design, these include; workability, strength and durability. It is the general practice that workability is related to the fresh concrete whereas durability and strength are hardened concrete properties (Vakhshouri & Nejadi, 2016). Therefore the methodology for testing of the concrete will be undertaken in two phases; the wet and hardened properties of the proposed mix design.

For the purpose of the dissertation 6 batches of concrete will be produced using general purpose (GP) cement, 20mm aggregate sourced from a local supplier and fine aggregates (sand) also sourced from a local supplier.

The compressions testing will be undertaken at the Russel Vale, Roads and Maritime Services laboratory which is a NATA approved facility and will also be supervised by a NATA endorsed tester. Modulus of Elasticity testing will be taking place at the Boral Testing Facility in Baulkham Hills, New South Wales.

4.2 Concrete Mix Design

The most important component of the mix design is the water/cement ratio. Notwithstanding the use of weaker aggregates within the mix, the lower the water/cement ratio the higher the compressive strength of the mix (USQ, 2012). For the purpose of this dissertation the nominated strength is 25MPa, therefore the adopted water/cement ratio for the purpose of the testing will be 0.65.

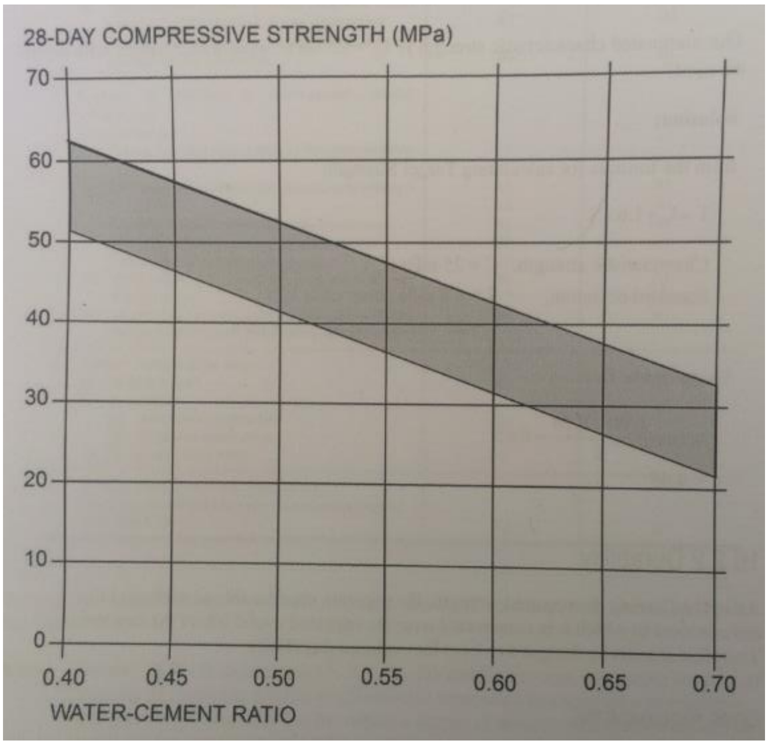


Figure 19: Water Cement ratio vs Strength (Type GP Cement) (Australia, 1994)

The workability of the concrete is highly influenced by the aggregate/cement ratio. The British Method of concrete mix design uses four aggregate grading's for the 20mm nominal sized aggregate. The required information when selecting the aggregate/cement ratio includes;

- Aggregate nominal size (20mm)
- Aggregate shape classification (crushed rock)
- Concrete slump (80mm)
- Water/cement ratio (0.65)
- Aggregate grading selected (curve No.3)

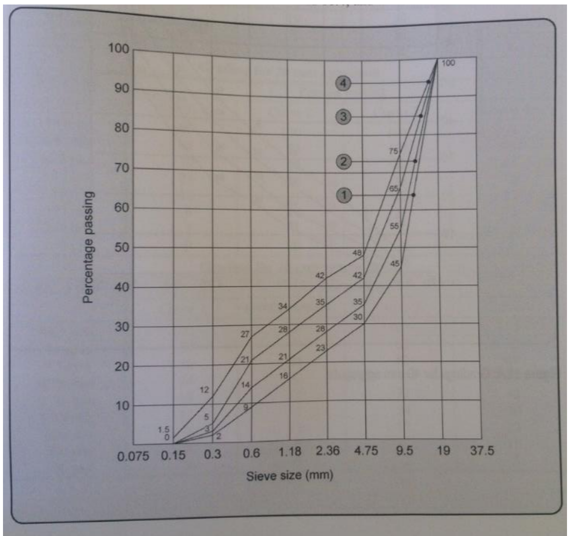


Figure 16.3: Gradings for 20 mm aggregate

Figure 20: 20mm Aggregate Grading Curves (USQ, 2012)

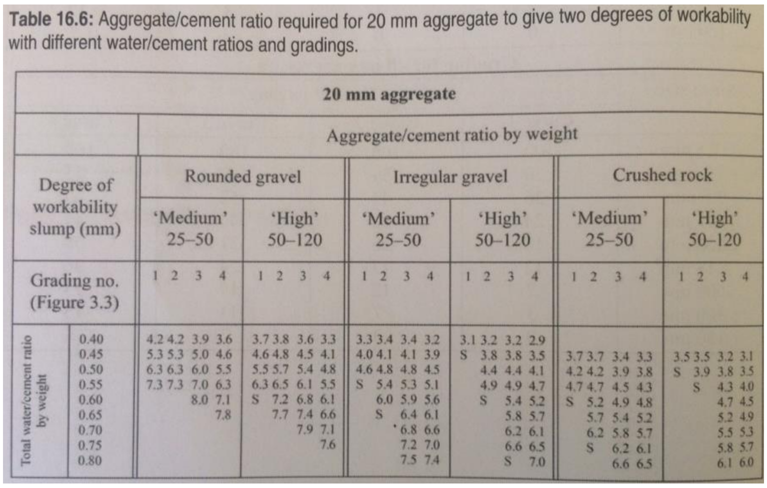


Table 16.6: Aggregate/cement ratio required for 20 mm aggregate to give two degrees of workability with different water/cement ratios and gradings.

20 mm aggregate — Aggregate/cement ratio by weight

Degree of workability slump (mm)	Rounded gravel 'Medium' 25–50				Rounded gravel 'High' 50–120			
Grading no. (Figure 3.3)	1	2	3	4	1	2	3	4
Total water/cement ratio by weight 0.40	4.2	4.2	3.9	3.6	3.7	3.8	3.6	3.3
0.45	5.3	5.3	5.0	4.6	4.6	4.8	4.5	4.1
0.50	6.3	6.3	6.0	5.5	5.5	5.7	5.4	4.8
0.55	7.3	7.3	7.0	6.3	6.3	6.5	6.1	5.5
0.60			8.0	7.1	S	7.2	6.8	6.1
0.65				7.8		7.7	7.4	6.6
0.70							7.9	7.1
0.75								7.6
0.80								

Degree of workability slump (mm)	Irregular gravel 'Medium' 25–50				Irregular gravel 'High' 50–120			
Grading no. (Figure 3.3)	1	2	3	4	1	2	3	4
Total water/cement ratio by weight 0.40	3.3	3.4	3.4	3.2	3.1	3.2	3.2	2.9
0.45	4.0	4.1	4.1	3.9	S	3.8	3.8	3.5
0.50	4.6	4.8	4.8	4.5		4.4	4.4	4.1
0.55	S	5.4	5.3	5.1		4.9	4.9	4.7
0.60		6.0	5.9	5.6		S	5.4	5.2
0.65		S	6.4	6.1			5.8	5.7
0.70			6.8	6.6			6.2	6.1
0.75			7.2	7.0			6.6	6.5
0.80			7.5	7.4			S	7.0

Degree of workability slump (mm)	Crushed rock 'Medium' 25–50				Crushed rock 'High' 50–120			
Grading no. (Figure 3.3)	1	2	3	4	1	2	3	4
Total water/cement ratio by weight 0.40								
0.45	3.7	3.7	3.4	3.3	3.5	3.5	3.2	3.1
0.50	4.2	4.2	3.9	3.8	S	3.9	3.8	3.5
0.55	4.7	4.7	4.5	4.3		S	4.3	4.0
0.60	S	5.2	4.9	4.8			4.7	4.5
0.65		5.7	5.4	5.2			5.2	4.9
0.70		6.2	5.8	5.7			5.5	5.3
0.75		S	6.2	6.1			5.8	5.7
0.80			6.6	6.5			6.1	6.0

Figure 21: Aggregate/cement ratio (USQ, 2012)

Therefore from the adopted information the required aggregate/cement ratio for the mix design will be 5.2. For the purposes of the dissertation there will be 6 batches of concrete tested with different proportions of aggregate and RAP used.

Table 5: Percentage of Aggregate/RAP used

	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6
Virgin Aggregate %	100	80	60	40	20	0
RAP %	0	20	40	60	80	100

Table 6: Concrete Mix Design Parameters

Target Strength (MPa)	25
Water/Cement Ratio	0.65
Aggregate/cement ratio	5.2

4.3 Calculation of Mix Design Quantities

From Table 2 determine the mix design proportions

- Cement = 1
- Water = 0.65
- Aggregate = 5.2

Multiply the mix proportions by the mass of one bag of cement 20kg and split the aggregate into different proportions; 20mm 36%, 10mm 23% and sand 39%.

Determine the proportions for the mix design based on the 20kg cement bag.

Table 7: Mix Design Proportions (kg)

	Mix Design Proportion	Aggregate Proportion	Mass of 1 bag of cement	Total (kg)
Cement	1		20	20
Water	0.65		20	13
20mm agg	5.2	0.36	20	37.44
10mm agg	5.2	0.23	20	23.92
Sand	5.2	0.39	20	40.56
Total				134.92

Therefore, based on a single bag of 20kg of cement the total mass of the batch will be 134.92kg then determine the amount based on the mixer's volume of 50 litres and the yield that will be produced from one 20kg bag of cement by multiplying the mass of each component by the specific gravity of the ingredient.

Table 8: Mix Design Proportions (litres)

	Quantity (kg)	Specific Gravity	Total	
Cement	20	3.15	6.3	litres
Water	13	1	13.0	litres
20mm agg	37.44	2.7	13.9	litres
10mm agg	23.92	2.7	8.9	litres
Sand	40.56	2.55	15.9	litres
20mm RAP	0	2.1	0.0	litres
Total			58.0	litres

There will be 6 batches produced for the purpose of the test with 3 requiring 5 cylinders with compression testing taking place at the 7 day, 14 day, 21 day and two at the 28 day mark and 3 requiring 11 cylinders and which will be for the 100% virgin aggregate, 40% virgin aggregate/60% RAP and 100% RAP for the purpose of one cylinder being tested for compression at 7 day, 14 day, 21 day and two at the 28 day. Further testing will be undertaken at the 28 day mark at the Boral Baulkham Hills facility where the modulus of elasticity will be tested at 40% of the compressive strength of the additional cylinders.

Therefore one bag of cement will produce 58 litres of concrete, to produce 29 litres of concrete to batch 11 cylinders the number of bags required are;

Number of bags = 29/58 = 0.5 bags

Therefore 10kg of cement will be required for each 29 litre batch.

To produce 17 litres of concrete for 5 cylinders the number of bags required are;

Number of bags = 17/58 = 0.30 bags

Therefore 5.86 kg of cement will be required for each 17 litre batch.

Table 9: Proportions of Virgin Aggregate and RAP

Batch	1(kg)	2(kg)	3(kg)	4(kg)	5(kg)	6(kg)
No. of Cylinders	11	5	5	11	5	11
Virgin agg	100	80	60	40	20	0
RAP	0	20	40	60	80	100

Table 10: Batch Quantities for Testing

Batch	1(kg)	2(kg)	3(kg)	4(kg)	5(kg)	6(kg)
Cement	10.00	5.86	5.86	10.00	5.86	10.00
Water	6.50	3.81	3.81	6.50	3.81	6.50
20mm agg	18.72	8.78	6.58	7.49	2.19	0.00
10mm agg	11.96	7.01	7.01	11.96	7.01	11.96
20mm RAP	0.00	2.19	4.39	11.23	8.78	18.72
Sand	20.28	11.88	11.88	20.28	11.88	20.28
Total	67.46	39.53	39.53	67.46	39.53	67.46

4.4 Fresh Concrete Testing

The plastic state properties of concrete are heavily influenced by the water /cement ratio and the aggregates proportions used in the mix design. The higher the water content in the mix the more workable the concrete will be in its plastic state, although this will also increase the potential for cracking from drying shrinkage.

The grading of the aggregates used within the mix also will influence the workability of the mix. This is why a smooth grading of aggregates is preferred in the mix design. The grading will therefore affect the workability, as the amount of water necessary to lubricate all the aggregate particles within the concrete matrix.

Aggregate particle size and shape will also affect the workability of the mix. Having a smooth or angular shaped aggregate will produce a more workable plastic state concrete whereas aggregates with a flaky or elongated shape would produce a less workable mix. The size of the aggregate will also have an effect on the workability, so a larger sized stone is preferred for a give water/cement ratio (Australia, 2000).

The plastic state testing to be done on the concrete batches will be the slump test. This will done in accordance with Australian Standard 1012 (2014) Methods of Testing Concrete.

4.4.1 AS1012.3.1 Methods of Testing Concrete – Determination of Properties Related to the Consistency of Concrete – Slump Test

- Apparatus
    - Hollow frustum with dimensions of;
        - bottom diameter 200mm ±5mm
        - top diameter 100mm ±5mm
        - vertical height 300mm ±5mm
    - Rod used for compacting

        - Length 600mm ±10mm
    - Scoop – not less than 1L capacity
    - Base plate
    - Ruler
- Sampling
    - Laboratory sampling
        - The test sample should be prepared in accordance with AS1012.2

- Procedure
    - Ensure internal surface of mould is clean
    - Moisten the internal surface of the frustum
    - Place the mould onto the base plate and fill the mould in three layers applying 25 strokes to each layer. Distribute the strokes evenly around the mould, ensure that when rodding the second and third layer allow the rod to penetrate into the underlying layer
    - At the completion of the top layer, remove the excess concrete so it remains flush with the top of the mould
    - Remove the mould from the concrete by slowly pulling the mould up vertically taking within 3 seconds ±1
    - Immediately take the slump of the concrete by measuring the sample next to the mould
- Measuring of slump
    - The slump shall be measured to the nearest 5mm for slumps less than 100mm (Limited, 2014a)

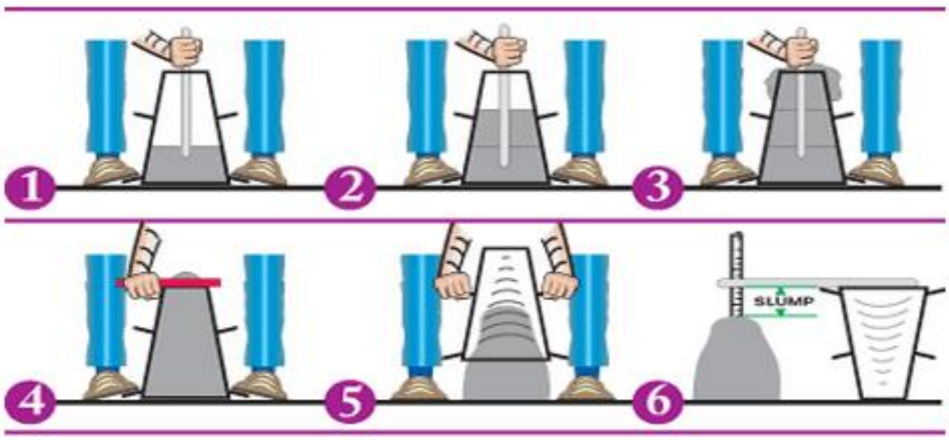


Figure 22: Concrete Slump Test Procedure (Constructor, 2016)

4.5 Hardened Properties

4.5.1 AS1012.8.1: Methods of Testing Concrete – Method for the Making and curing Concrete - Compression and Indirect Tensile Test

- Sampling
    - Test sample shall be prepared in accordance with AS1012.2
    - The diameter of the sample shall be between 95mm and 105mm for the nominal sample of 100mm with the nominal aggregate size not being greater than 20mm
    - The shape of the sample shall be a right cylinder with dimensions of between 1.95 and 2.05 the diameter of the sample
- Equipment
    - Cylinder moulds shall be clampable and have a height of between 1.95 and 2.05 the diameter of the diameter
    - The surface of the base plate shall not vary from a plane by more than ±0.05mm
    - Rod for the compaction shall comply with the relevant Australian Standard AS1012.3.1, AS1012.3.2 and AS1012.3.3
    - Mallet shall comply with the relevant Australian Standard AS1012.4.1, AS1012.4.2 and AS1012.4.3
    - The scoop shall have a nominal capacity of no less than 1L or greater
- Moulding
    - Rodding of the sample shall be used due to the design slump being 80mm
    - Lightly apply release agent to all exposed surfaces of the moulds that will be in direct contact with the concrete
    - After sample has finished mixing take the sample to the location of moulding and undertake workability tests AS1012.3.1 Slump test and AS1012.3.2 Compacting Factor Test
    - Place prepared concrete into the pre-prepared moulds in three approximately equal layers providing 25 strokes per layer, for each overlying layer penetrate into the layer below for at least the first 10 strokes
    - Close any holes in the layer by lightly tapping the sides of the mould with the mallet
    - Ensure to place sufficient concrete into the last layer to completely fill the mould and strike of any excess concrete at the completion of the compaction procedure
    - Each sample shall be uniquely marked for identification
- Curing
    - For the Standard Temperate Zone, samples shall be stored in there moulds in a room with a maintained temperature of 23 ±2°C for initial curing to take place for a period of not less than 18 hours and not more than 36 hours.
    - Moist curing shall then take place by placing the samples into a lime saturated water bath with a temperature range of 23 ±2°C

- Unless testing is to take place within the first 18-36 hours specimens are to stay in the moist curing conditions until required for testing (Limited, 2014b)

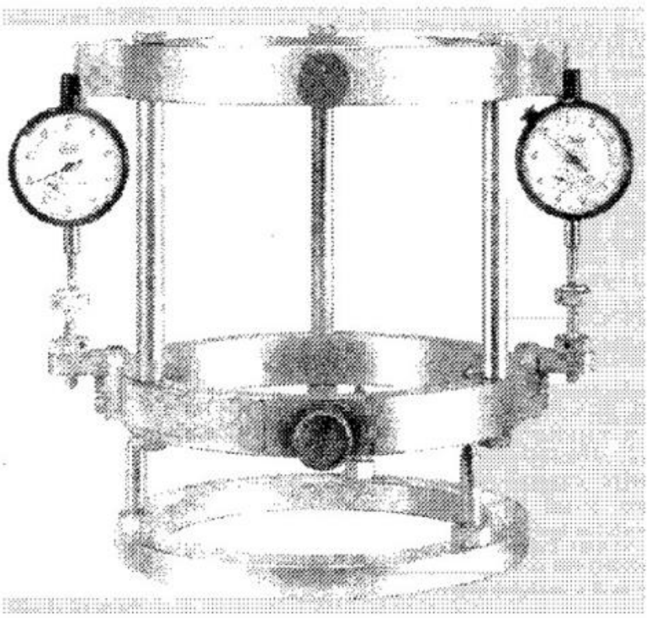
4.5.2 AS1012.9: Methods of Testing Concrete – Compressive Strength Tests – Concrete, Grout and Mortar Specimens

- Samples
  - Samples are to be moulded in accordance with AS1012.8.1
  - Samples to be tested are to be kept moist until inspection, capping and crushing is to be undertaken, all test shall be performed within 2 hours of removal from moist curing conditions
  - Capping of specimens is to be done using a restrained natural rubber pad
  - The rubber pad shall be a nominal 110mm diameter and have a uniform thickness of between 12mm and 15mm
  - Capping shall be placed on the test sample just prior to testing is to take place
  - Ensure that the pad, sample and restraining device are concentric in the testing apparatus
  - Ensure that no part of the concrete sample is in contact with the testing apparatus see Figure 23
- Testing procedure
  - Ensure that the testing of the sample commences within 2 hour of removal from the moist curing conditions
  - Wipe all excess water from the sample prior to beginning testing
  - Clean the platens of the machine and ensure that the sample is centrally located within the machine prior to beginning testing
  - Bring the upper platen onto the capped surface of the specimen so that is bearing onto the top of the sample
  - Apply the force to the sample at a constant force of 20 ±2MPa until the sample can take no more force and fails
  - Record the maximum force indicated by the testing machine
- Calculation
  - The final compressive strength shall be obtained by dividing the maximum force applied to the sample by the mean of the cross sectional area of the sample when taking two readings (Limited, 2014c)

Figure 23: Compression Testing Machine (Research, 2016)

4.5.3 AS1012.17: Methods of Testing Concrete – Determination of the static chord Modulus of Elasticity and the Poisson's Ratio of Concrete Specimens

- Apparatus
  - The apparatus used for the testing of the compressive strength of the sample shall be in accordance with AS1012.9
  - The deformation measuring apparatus shall be capable of measuring the deformation of the sample to the nearest 10 x 10^{-6} m/m. See Figure 24. Both yokes should be rigidly attached to the sample in at least three spots



NOTE: Note the jig and positioning rods used to centre the compressometer before clamping.

Figure 24: Typical Compressometer Arrangement for Measurement of the Longitudinal Strain (Limited, 1997)

- Test Specimens
    - Moulded cylinders in accordance with AS1012.9
    - No fewer than three samples shall be used to for each determination of the modulus of elasticity and no fewer than two samples shall be used for the mean compressive strength of the samples
    - Samples shall be capped, except that a rubber capping system shall not be used
- Procedure
    - The procedure to be adopted for the purposes of this dissertation shall be Method 1 of AS1012.17
    - The test shall be taken as 40% of the mean compressive strength of the not less than two companion samples
    - Testing shall be done on as close as possible to the compressive testing or preferably the same day
- Loading Procedure
    - Record the temperature and the relative humidity at the time the test is to be undertaken. Testing shall be completed no longer than 30 minutes after the sample has been removed from its curing condition
    - Measure each sample and place and place on the lower platen of the machine and attach the gauges in accordance with the specifications of the jig
    - Lower the top platen onto the sample so that the load is taken and is seated properly
    - Load the specimen at least three times and ensuring the first loading is recorded
    - Apply the loading at a constant rate of 15±2 MPa/Min
    - Record the applied load when sample is subjected to a longitudinal strain of 50 x 10^{-6} m/m and the test load of 40% of the compressive strength
    - Record the test load and then reduce the load back to zero at approximately the same rate as loading occurred
    - To obtain a stress/strain curve take intermediate readings without any interruption to the loading cycle
- Determination of the Modulus of Elasticity
    - Recording measurements as per previous loading procedure
    - G_1 = applied load at a strain of 50 x 10^{-6} divided by the cross sectional area of the unloaded sample, results in MPa
    - G_2 =the test load divided by the cross sectional area of the unloaded sample, results in MPa
    - ε_2 = deformation at the test load divided by the gauge length in 10^{-6} m/m
- Calculation
    - $E = \frac{(G_1 - G_2}{(\varepsilon_2 - 0.0005)}$ MPa

5 RESULTS AND DISCUSSIONS

5.1 Introduction

A series of testing was undertaken on the design mix using different proportions of RAP as an aggregate replacement. All the testing that was done was in accordance with the relevant Australian Standards and were undertaken at a NATA approved laboratory located in Bellambi, New South Wales. These tests were done to ascertain the effects that the RAP would have on the plastic state concrete e.g. workability, and the hardened state properties including; compressive strength and the Modulus of Elasticity.

Due to the limitations of the laboratory facilities the coarse and fine aggregates are assumed as being in their saturated surface dry condition (SSD). As such the moisture contents of the sand, 10mm aggregate, 20mm aggregate and the 20mm RAP are;

- Sand – 7.1%
- 10mm aggregate – 2.6%
- 20mm aggregate – 2.7%
- 20mm RAP – 2.0%

There was an initial Batch 1 produced were the moisture contents of the aggregates were not accounted for and the total 11 cylinders were produced for testing. As this was picked up too late another Batch 1 was produced were a total of 5 cylinders were produced and only the compression testing could be completed.

5.2 Adjusted Mix Design

Table 11: Material Moisture Contents

Moisture Contents (%)			
Sand	10mm Aggregate	20mm Aggregate	RAP
7.1	2.6	2.7	2

As the materials were assumed to SSD the amount of water contained within the materials was then subtracted from the design water amounts and a final mix design was determined for testing.

Table 12: Moisture in SSD Materials

	Sand	10mm Aggregate	20mm Aggregate	RAP
Batch 1 (kg)	0.720	0.155	0.253	0.000
Batch 2 (kg)	0.844	0.182	0.237	0.044
Batch 3 (kg)	0.844	0.182	0.178	0.088
Batch 4 (kg)	1.440	0.311	0.202	0.225
Batch 5 (kg)	0.844	0.182	0.059	0.176
Batch 6 (kg)	1.440	0.311	0.000	0.374

Table 13: Adjusted Mix Design

Batch	1(kg)	1(kg)[1]	2(kg)	3(kg)	4(kg)	5(kg)	6(kg)
	Water content unadjusted	Water content adjusted					
Cement	12.50	5.00	5.86	5.86	10.00	5.86	10.00
Water	6.50	3.25	3.81	3.81	6.50	3.81	6.50
Actual water added	6.50	2.12	2.50	2.52	4.32	2.55	4.37
20mm agg	29.25	9.36	8.78	6.58	7.49	2.19	0.00
10mm agg	18.69	5.98	7.01	7.01	11.96	7.01	11.96
20mm RAP	0.00	0.00	2.19	4.39	11.23	8.78	18.72
Sand	31.69	10.14	11.88	11.88	20.28	11.88	20.28
Total	105.13	35.85	42.03	42.05	71.78	42.08	71.83

5.3 AS1012.3.1 Slump Test

The slump test is a measure of the workability of the concrete in its plastic state. This property can be affected by the aggregate size and shape. The test results for the slump can be found in Table 14 and Figure 25. The design slump for the batch is to be 80mm ±20mm.

Due to an error in the first batch of Batch 1, no adjusted moisture content was adopted and the full amount of water was added to the batch this greatly affected the slump of the batch and due to this error another batch was produced for the purpose of the test.

Table 14: Slump results as per AS1012.3.1

	Batch 1 (unadjusted)	**Batch 1 (adjusted)**	**Batch 2**	**Batch 3**	**Batch 4**	**Batch 5**	**Batch 6**
Virgin Aggregate %	100	100	80	60	40	20	0
RAP %	0	0	20	40	60	80	100
Slump (mm)	220	90	75	90	95	65	100

[1] Batch 1 with the water content adjusted is identified as Batch 7 in the Russel Vale Laboratory Report

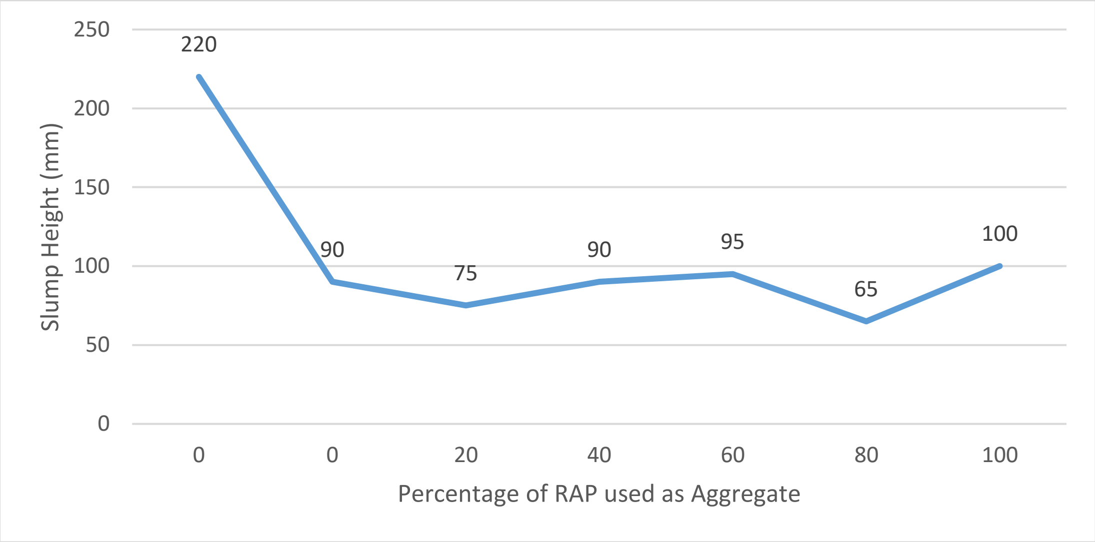


Figure 25: Slump Results as per AS1012.3.1

As can be seen from Table 14 and Figure 25 the inclusion of the RAP in different proportions did not appear to affect the plastic state properties of the batched concrete as all the samples apart from the initial Batch 1 where no adjusted moisture content was taken into consideration fell within the design slump of 80mm ±20mm.

Figure 26: Slump Testing in accordance with AS1012.3.1

Figure 27: Slump testing of fresh concrete in accordance with AS1012.3.1

5.4 AS1012.9: Compressive Strength Tests

The design strength for the project was 25MPa, as can be seen from the results the amount of included RAP in the mix does affect the compressive strength properties of the concrete. All the specimens had the typical strength gains over the 28 day period with an initial high strength gain in the first 7 days then levelling out towards the 28 day mark.

It is evident from Table 15 and Figure 28 that the inclusion of RAP into the concrete batch will affect the compressive strength properties of the concrete samples. Batch 1 (adjusted) was used as the baseline mix with 100% virgin aggregate and this batch had gained the design strength within the first 7 days from batching. Batch 2, 3 and 4 then progressively gained the required design strength between the 14 and 28 day period respectively.

Batch 5 and 6 did not reach the design 25 MPa at the 28 day mark, this could be due to the physical properties of the included RAP as weaker aggregates incorporated into the batch will affect the hardened state properties of concrete.

Figure 29 indicates that the additional water added to the unadjusted Batch 1 did affect the hardened properties of the concrete as it had a lower compressive strength compared to the adjusted Batch 1 over the entire 28 day period. This Batch was still included in the analysis due to the limitations of the laboratory and the quantity of materials procured for the dissertation.

Table 15: Compressive Strength of Samples

	Batch 1 (unadjusted)	Batch 1[2] (adjusted)	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6
RAP %	0	0	20	40	60	80	100
Day			Compressive strength (MPa)				
3	16.5				16		15
7	23	28.5	24.5	21.5	20	20.5	19
14	28.5	33.5	32	25	23.5	22.5	20.5
21	31	36.5	33	27	24	23.5	21
28	34	37.5	35	28	25	24.25	21.75

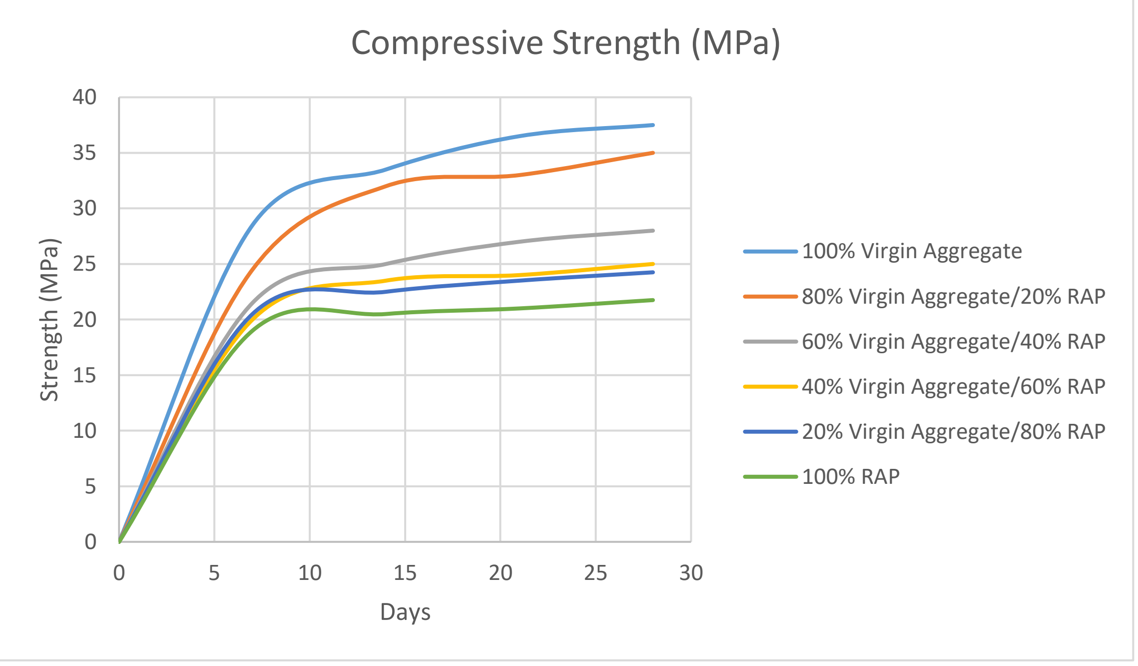


Figure 28: Plot of Compressive Strength Data

[2] Batch 1 (adjusted) is identified as Batch 7 in the Russel Vale Laboratory Report

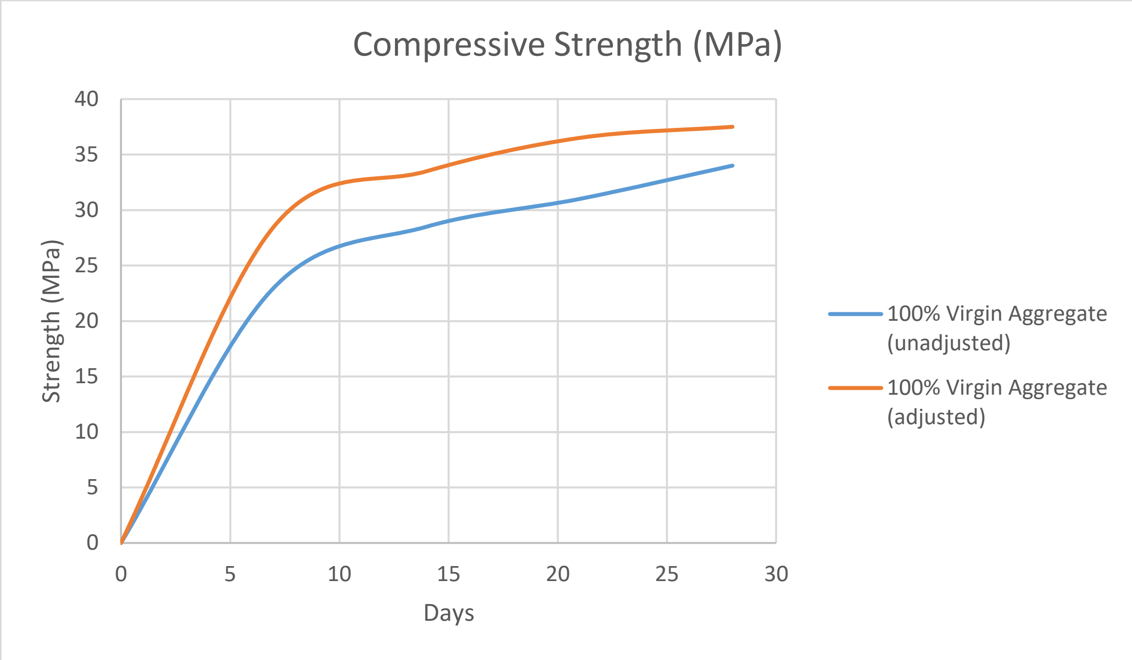


Figure 29: Compressive Strength of Adjusted and Unadjusted Batch 1

Figure 30: Batch 1 (adjusted) 28 day crushed sample

Figure 31: Batch 2 28 day crushed sample

Figure 32: Batch 3 28 day crushed sample

Figure 33: Batch 4 28 day crushed sample

Figure 34: Batch 5 28 day crushed sample

Figure 35: Batch 6 28 day crushed sample

As can be seen from Figure 30 to Figure 35 the inclusion of the RAP samples did not affect the method of failure under the compression loading. There appeared to be no pattern in the method as the failure as they all failed in different modes e.g. splitting and shear or a combination of both.

For the purposes of the project Batch 1 was used as the baseline for the amount of compressive strength remaining in the samples over the 6 batches with each containing different percentages of RAP. From Table 16 and Figure 36 you can see that with an increase in RAP content there is a significant difference in the compressive strength of the samples when tested at 28 days.

The compressive strength of the samples had dropped 42% between the baseline 100% virgin aggregate to the 100% RAP. This could be due to the amount of bitumen content contained within the included RAP as the level of oxidation would lead to a more brittle aggregate leading to a weaker aggregate within the concrete matrix.

Table 16: Percentage of Compressive Strength Remaining

	Batch 1 (adjusted)	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6
RAP %	0	20	40	60	80	100
Remained Compressive Strength (%)	100	93	74	65	64	58
Dropped Compressive Strength (%)	0	7	26	35	36	42

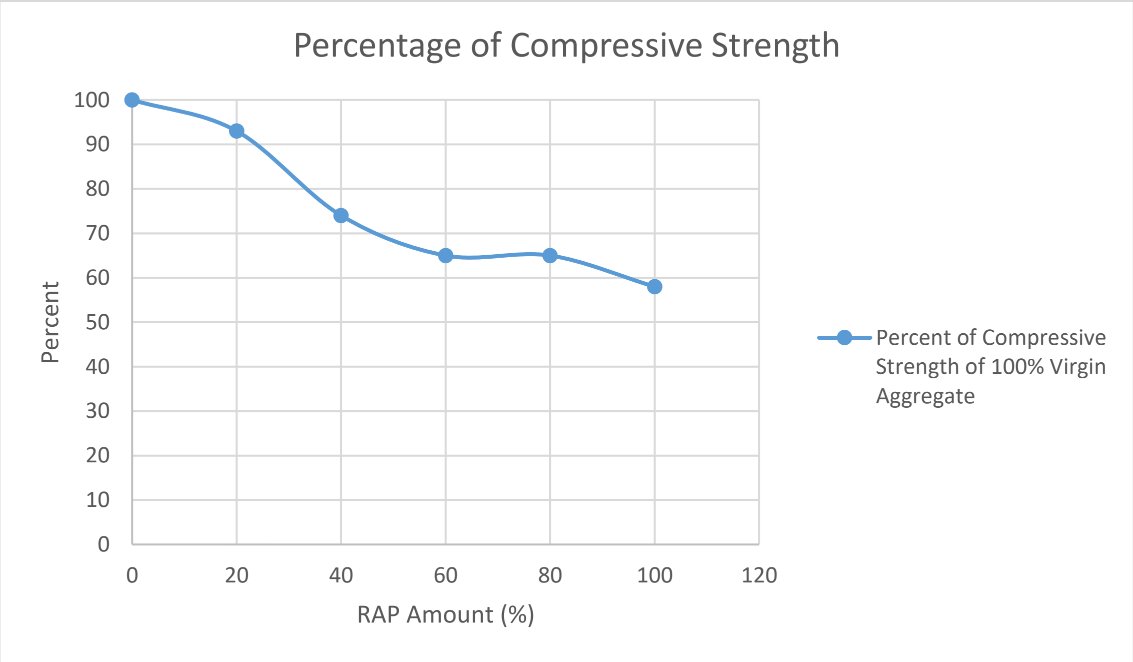


Figure 36: Percent of Compressive Strength Compared to Baseline Sample of 100% Virgin Aggregate

5.5 AS1012.17: Modulus of Elasticity and Poisson's Ratio

With the increase in RAP to the batches the modulus of elasticity decreased. The results from the unadjusted Batch 1 were used for the testing. Due to the laboratories limitations, enough samples were not produced in the second attempt at Batch 1 for the modulus testing.

Extrapolating the results for the 40% virgin aggregate/60% RAP (Batch 4) and 100% RAP (Batch 6) and adopting the unadjusted Batch 1 results, it can be seen that the modulus decreases with an increase in RAP.

Table 17 shows that Batch 1 (unadjusted) had a modulus of elasticity of 24.7GPa whereas Batch 6 had a modulus of elasticity of 17.1GPa, this is a drop of 7.6GPa or 30% of the modulus with the inclusion of the 100% RAP aggregate. This amount could have been more if the adjusted Batch 1 was used as the baseline quantity.

Table 17: Modulus of Elasticity (GPa)

	Batch 1 (unadjusted)	Batch 4	Batch 6
RAP %	0	60	100
Modulus of Elasticity (GPa)	24.7	19.6	17.1

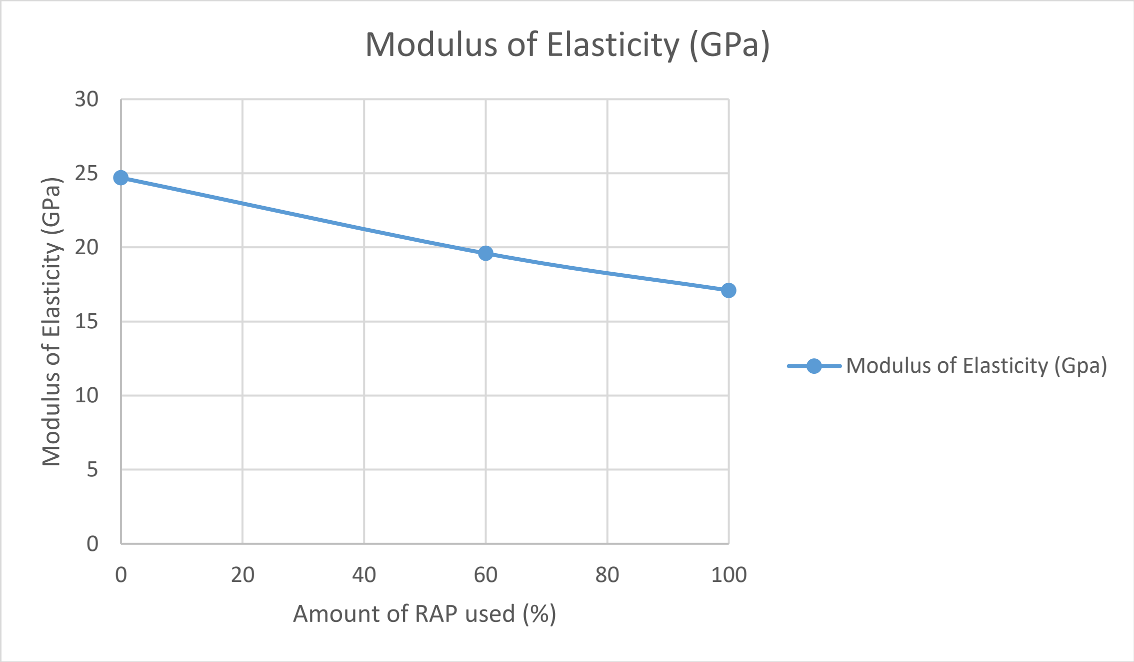


Figure 37: Modulus of Elasticity

Table 18: Poisson's Ratio

	Batch 1 (unadjusted)	Batch 4	Batch 6
RAP %	0	60	100
Poisson's Ratio	0.154	0.142	0.141

As can be seen from Table 18 the inclusion of RAP does not adversely affect the Poisson's Ratio of the concrete specimens, the average Poisson's Ratio normally lays within the range of 0.1to 0.2.

6 CONCLUSIONS

Researching and determining the suitability of recycled materials for use in the construction industry is an important tool due to the ongoing need for infrastructure assets. Currently RAP is mainly being used in the asphalt industry with not as much inclusion as a base coarse material. Having the ability to find alternative uses for the RAP material including in the concrete industry could reduce the need for virgin aggregates in the production of the concrete.

Based on the result of this research project, the inclusion of RAP into a design mix would be feasible. This dissertation only looked to use the RAP in a 25MPa design mix utilising a high water/cement ratio of 0.65:1. Based on the compression testing results, for an economical mix where a mixture of both virgin aggregate and RAP were to be used, a ratio of 50:50 would be deemed the most suitable. This is due to the 60% virgin aggregate/40% RAP and the 40% virgin aggregate/60% RAP both achieving the design 25MPa at the 28 day mark.

The plastic state properties of the concrete did not appear to be affected by the inclusion of the RAP as the slump tests all fell within the design slump of 80mm ±20mm. As the aggregates were assumed to be in the SSD state further testing could be undertaken where the water absorption rates of the aggregates are determined and the compactability test could be done to further define what affects the inclusion of the RAP has on the workability of the concrete.

It should be noted that further testing on the RAP could be done to refine the results and determine if the bitumen content and level of oxidation of the RAP will adversely affect the results.

Further testing that could be undertaken would include;

- Indirect tensile testing (Brazil)
- Creep
- Shrinkage

As this dissertation only investigated the replacement of the 20mm portion of the concrete, further research could be done where the RAP is sieved done into the finer fractions and utilising this material to replace the finer fractions e.g. sand in the mix.

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8 APPENDIX A PROJECT SPECIFICATION

ENG4111/4112 Research Project

Project Specification

For: Robert Wiya

Title: Behaviour of concrete when using reclaimed asphalt pavement (RAP) as

an aggregate material.

Major: Civil Engineering

Supervisors: Yan Zhuge

Enrolment: ENG4111 – EXT S1, 2016

ENG4112 – EXT S2, 2016

Project Aim: To determine if the use of RAP as a coarse aggregate replacement will affect the hardened properties of the concrete in a positive or negative way.

Programme: Issue A, 12th March 2016

1. Research information relating to sustainable concrete, asphalt and recycled aggregates.

2. Batch 14mm 25MPa concrete specimens with different proportions of RAP used as a coarse aggregate replacement e.g. 0, 20, 40, 60, 80 and 100%.

3. Undertake compression testing at 1, 7, 14 and 28 days.

4. Undertake indirect tensile test and the modulus of elasticity test after 28 days.

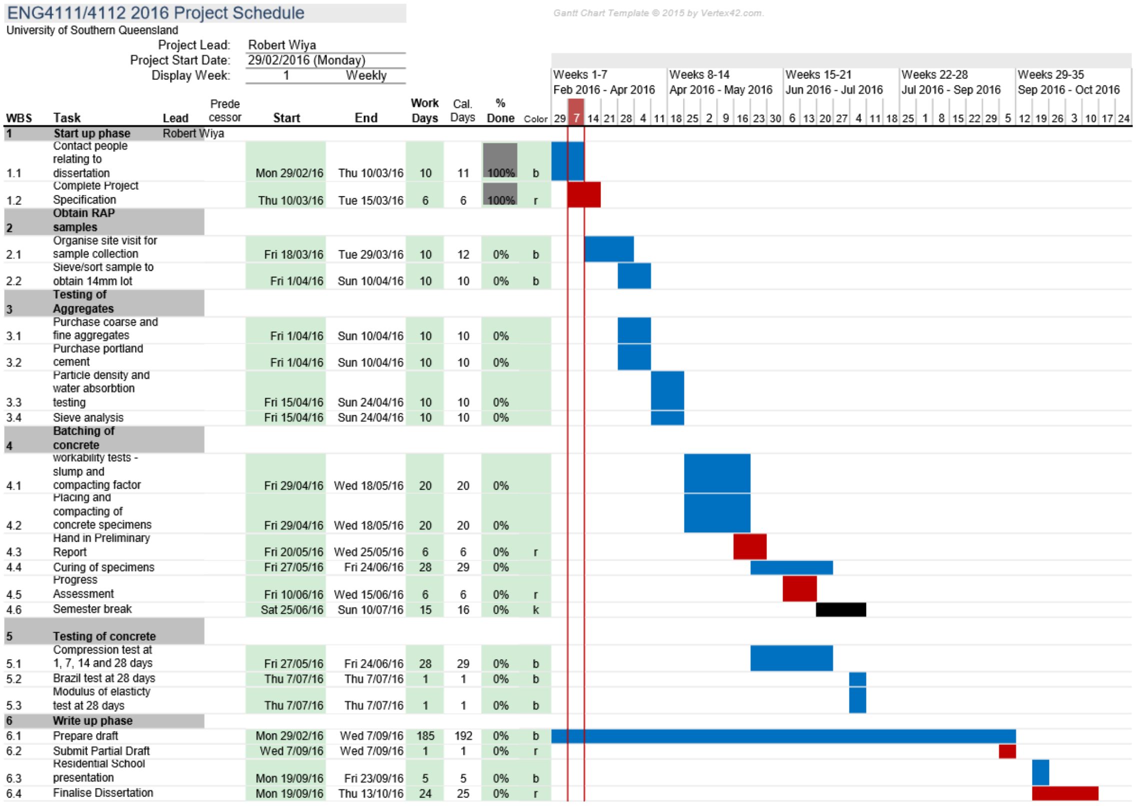
5. Evaluate and analyse data findings.

6. Compare results with lab testings of 20mm 25MPa concrete of batches containing virgin aggregate and recycled crushed aggregates.

If time and resources permits:

7. Research on optimal mix design.

9 APPENDIX B PROJECT SCHEDULE



ENG4111/4112 2016 Project Schedule
University of Southern Queensland
Project Lead: Robert Wiya
Project Start Date: 29/02/2016 (Monday)
Display Week: 1 Weekly

WBS	Task	Lead	Predecessor	Start	End	Work Days	Cal. Days	% Done	Color
1	**Start up phase**	Robert Wiya							
1.1	Contact people relating to dissertation			Mon 29/02/16	Thu 10/03/16	10	11	100%	b
1.2	Complete Project Specification			Thu 10/03/16	Tue 15/03/16	6	6	100%	r
2	**Obtain RAP samples**								
2.1	Organise site visit for sample collection			Fri 18/03/16	Tue 29/03/16	10	12	0%	b
2.2	Sieve/sort sample to obtain 14mm lot			Fri 1/04/16	Sun 10/04/16	10	10	0%	b
3	**Testing of Aggregates**								
3.1	Purchase coarse and fine aggregates			Fri 1/04/16	Sun 10/04/16	10	10	0%	
3.2	Purchase portland cement			Fri 1/04/16	Sun 10/04/16	10	10	0%	
3.3	Particle density and water absorbtion testing			Fri 15/04/16	Sun 24/04/16	10	10	0%	
3.4	Sieve analysis			Fri 15/04/16	Sun 24/04/16	10	10	0%	
4	**Batching of concrete**								
4.1	workability tests - slump and compacting factor			Fri 29/04/16	Wed 18/05/16	20	20	0%	
4.2	Placing and compacting of concrete specimens			Fri 29/04/16	Wed 18/05/16	20	20	0%	
4.3	Hand in Preliminary Report			Fri 20/05/16	Wed 25/05/16	6	6	0%	r
4.4	Curing of specimens			Fri 27/05/16	Fri 24/06/16	28	29	0%	
4.5	Progress Assessment			Fri 10/06/16	Wed 15/06/16	6	6	0%	r
4.6	Semester break			Sat 25/06/16	Sun 10/07/16	15	16	0%	k
5	**Testing of concrete**								
5.1	Compression test at 1, 7, 14 and 28 days			Fri 27/05/16	Fri 24/06/16	28	29	0%	b
5.2	Brazil test at 28 days			Thu 7/07/16	Thu 7/07/16	1	1	0%	b
5.3	Modulus of elasticty test at 28 days			Thu 7/07/16	Thu 7/07/16	1	1	0%	b
6	**Write up phase**								
6.1	Prepare draft			Mon 29/02/16	Wed 7/09/16	185	192	0%	b
6.2	Submit Partial Draft			Wed 7/09/16	Wed 7/09/16	1	1	0%	r
6.3	Residential School presentation			Mon 19/09/16	Fri 23/09/16	5	5	0%	b
6.4	Finalise Dissertation			Mon 19/09/16	Thu 13/10/16	24	25	0%	r

Figure 38: Project Schedule

10 APPENDIX C RESOURCE REQUIREMENTS

Need to purchase:

General purpose Portland cement (GP)

20mm (virgin) aggregate

Sand

Need to obtain:

Reclaimed asphalt pavement (RAP) – this can be sourced from Roads and Maritime Services (RMS)

Facilities:

Russel Vale Laboratory – batching, curing and testing to take place here

11 APPENDIX D RISK ASSESSMENT

UNIVERSITY OF SOUTHERN QUEENLAND	FACULTY OF HEALTH, ENGINEERING AND SCIENCE
Title: BEHAVIOR OF CONCRETE WHEN USING RAP (RECLAIMED ASPHALT PAVEMENT) AS A COARSE AGGREGATE MATERIAL	
Location: Bellambi/Russel Vale	Dates: August 2016 – September 2016
Name: Robert Wiya	
Brief objective: To test what effects the use of RAP has on the plastic and hardened state properties of concrete when used as coarse aggregate replacement.	

PART 2: HAZARDS

HAZARD	INTIAL RISK	CONTROL MEASURES	RISK
Sourcing RAP			
Moving plant	Extreme	• Site induction • Positive communications • PPE	Low
Slips, trips and falls	Moderate	• Aware of location of walking	Low
Shovelling RAP into containers	Moderate	• Using correct method to shovel	Low
Lifting	Moderate	• Correct lifting techniques	Low

HAZARD	**INTIAL RISK**	**CONTROL MEASURES**	**RISK**
Batching concrete			
Shovelling	Moderate	• Using correct method to shovel	Low
Working with cement	Moderate	• PPE	Low
Slips, trips and falls	Moderate	• Aware of location of walking	Low
Making cylinders of concrete	Moderate	• PPE • Using correct method to shovel	Low
Lifting cylinders into water bath	Moderate	• Correct lifting techniques	Low

HAZARD	INTIAL RISK	CONTROL MEASURES	RISK
Crushing cylinders			
Lifting cylinders out of water bath and placing into crushing apparatus	Moderate	• Correct lifting techniques	Low
Slips, trips and falls	Moderate	• Aware of location of walking	Low
Using crushing machine	Moderate	• Induction how to use machine correctly • PPE	Low

PART 3: RISK ASSESSMENT MATRIX

LIKELIHOOD	**CONSEQUENCE**				
	INSIGNIFICANT	**MINOR**	**MODERATE**	**MAJOR**	**CATASTOPHIC**
ALMOST CERTAIN	High	High	Extreme	Extreme	Extreme
LIKELY	Moderate	High	High	Extreme	Extreme
MODERATE	Low	Moderate	High	Extreme	Extreme
UNLIKELY	Low	Low	Moderate	High	Extreme
RARE	Low	Low	Moderate	High	High

PART 4: ADDITONAL INFORMATION

PPE required: Hi-vis clothing, radio, glasses, dust mask, earplugs, steel cap boots
Emergency and First Aid: nominated first aid person at the stockpile facility and laboratory. Emergency procedures to be confirmed at induction to facilities.

12 APPENDIX E MOISTURE CONTENT RESULTS

Encore Document - DAT009 - Rev 1 - 18/6/2015 Page of .

Roads and Maritime Services

Southern - Russell Vale - 21 York Place,Russell Vale, 2517

Worksheet - Determination of Moisture Content of a Soil

Test Method - T120

Registration Number	R00786

Equipment

Balance	48344	Oven	19012

Ensure the currency of T2105 if using corrections for moisture contents determined by methods other than T120

Sample No.:	Sand	10mm	20mm	RAP	
Dish No.:	63	56	58	23	
Mass of Dish (M1) (g)	1008.3	1025	953	1015.9	
Mass of Wet Soil + Dish (M2) (g)	1733.5	2511.5	3455.1	3580.4	
Mass of Dry Soil + Dish (g)	1685.2	2474.3	3388.6	3529.6	
Mass Dry Soil + Dish (g) (Repeat 1) (M3)	1685.2	2474.3	3388.6	3529.6	
Mass Dry Soil + Dish (g) (Repeat 2) (M3)	1685.2	2474.3	3388.6	3529.6	
Moisture Content (%) *(W or Wu) = ((M2-M3)/(M3-M1)x100)*	7.1	2.6	2.7	2	
Correlation intercept from T2105 (A)					
Correlation gradient from T2105 (B)					
Corrected Moisture Content (%) *[W] = (A+(BxWu)) (%)*					
Tested By / Date	GS 22/8/16	GS 22/8/16	GS 22/8/16	GS 22/8/16	
Checked By / Date	GS 23/8/16	GS 23/8/16	GS 23/8/16	GS 23/8/16	

Sample No.:					
Dish No.:					
Mass of Dish (M1) (g)					
Mass of Wet Soil + Dish (M2) (g)					
Mass of Dry Soil + Dish (g)					
Mass Dry Soil + Dish (g) (Repeat 1) (M3)					
Mass Dry Soil + Dish (g) (Repeat 2) (M3)					
Moisture Content (%) *(W or Wu) = ((M2-M3)/(M3-M1)x100)*					
Correlation intercept from T2105 (A)					
Correlation gradient from T2105 (B)					
Corrected Moisture Content (%) *[W] = (A+(BxWu)) (%)*					
Tested By / Date					
Checked By / Date					

13 APPENDIX F SIEVE ANALYSIS RESULTS

ROADS AND MARITIME SERVICES

Aggregate

Transport Roads & Maritime Services

NSW Government

Russell Vale Laboratory
21 York Place
Russell Vale NSW 2518
T: (02) 4222 3242
F: (02) 4222 3240
PO Box 62 Corrimal NSW 2518

Laboratory Test Report

Report: **R00786** Part 02

AGG Record No:	42
Recieved:	10/08/2016
Sampled By:	GS
Sampling Method:	AS1141.3.1 [8.4.3]
Material:	Aggregate
Request Id:	

Client:	Roads and Maritime Services - Robert Wiya
Address:	90 Crown Street, Wollongong, NSW 2500
Client Ref:	
Lab Ref (Project):	
Project Description:	Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate.
Work Details:	Concrete Testing.
Work Distance:	*
Supplier:	

SPECIFIED LIMITS:		Sample:	10mm	20mm	RAP	Sand
	Date Sampled:		18/08/2016	18/08/2016	10/08/2016	18/08/2016
	Sample Represents:		10mm Agg	20mm Agg	RAP	Sand
	Quantity Represented:		*	*	*	*
	Lot Number:		*	*	*	*
	Sample Chainage (km) or Location:		Baines	Baines	RMS SP	Baines
	Lane:		*	*	*	*
	Offset (m):		*	*	*	*
	Nominal Size:		10	20	20	5
TESTS	PRETREATMENT		*	*	*	*
AS1141.11.1	Passing 75.0mm Sieve(%):		100	100	100	100
	Passing 63.0mm Sieve(%):		100	100	100	100
	Passing 53.0mm Sieve(%):		100	100	100	100
	Passing 37.5mm Sieve(%):		100	100	100	100
	Passing 26.5mm Sieve(%):		100	100	100	100
	Passing 19.0mm Sieve(%):		100	95	53	100
	Passing 13.2mm Sieve(%):		100	63	3.0	100
	Passing 9.50mm Sieve(%):		93	18	0.5	100
	Passing 6.70mm Sieve(%):		54	7.0	0.5	100
	Passing 4.75mm Sieve(%):		19	4.0	0.0	100
	Passing 2.36mm Sieve(%):		5.0	3.0	0.0	93
	Passing 1.18mm Sieve(%):		3.0	3.0	0.0	82
	Passing 600µm Sieve(%):		2.5	2.5	0.0	64
	Passing 425µm Sieve(%):		2.5	2.5	0	48.7
	Passing 300µm Sieve(%):		2.6	2.6	0.0	32.5
	Passing 150µm Sieve(%):		2.4	2.5	0.0	7.5
	Passing 75µm Sieve(%):		2.2	2.5	0.0	2.5
T213	Caliper Ratio(2:1/3:1):		* *	* *	* *	* *
	Flat (%):		* *	* *	* *	* *
	Elongated(%):		* *	* *	* *	* *
	Flat and Elongated (%):		* *	* *	* *	* *
	Mis-Shapened(%):		* *	* *	* *	* *
T215	Size Tested(mm):		*	*	*	*
	Dry Strength(kN):		*	*	*	*
	Wet Strength(kN):		*	*	*	*
	Wet Dry Variation (%):		*	*	*	*
*	Avg. Least Dimension(mm):		*	*	*	*
*	Avg. Least Dimension(mm):		*	*	*	*

Report Comments:-

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Accredited for Compliance with ISO/IEC 17025

Accreditation Number: 2599

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Glenn Smith
A/Laboratory Manager
Date: 15/09/2016

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14 APPENDIX G COMPRESSION TEST RESULTS

ROADS AND MARITIME SERVICES

Concrete

Transport Roads & Maritime Services

Russell Vale Laboratory
21 York Place
Russell Vale NSW 2518
T: (02) 4222 3242
F: (02) 4222 3240
PO Box 62 Corrimal NSW 2518

Laboratory Test Report

Report: **R00786** Part 01

CON Record No: 280	Client: Roads and Maritime Services - Robert Wiya		
Received: 23/08/2016	Address: 90 Crown Street, Wollongong, NSW 2500		
Sampled By: GS	Client Ref:	Lab Ref (Project):	
Sampling Method: AS1012.1 [7.2]	Project Description: Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate.		
Material: Concrete	Work Details: Concrete Testing.		
Request Id:	Work Distance: *		
	Supplier:		

Test Method		B1	B1	B1	B1
	Sample Id:	**B1**	**B1**	**B1**	**B1**
	Date Sampled:	23/08/2016	23/08/2016	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*	*	*
	Lot Distance End(km):	*	*	*	*
	Batch Number:	Batch 1	Batch 1	Batch 1	Batch 1
	Sample Chainage (km) or Location:	RV Lab	RV Lab	RV Lab	RV Lab
	Sample Represents:	TRIAL 1	TRIAL 1	TRIAL 1	TRIAL 1
	Quantity Represented(m^3):	*	*	*	*
	Lane:	*	*	*	*
	Offset(m):	*	*	*	*
	Depth(mm):	* - *	* - *	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*	*	*
Test Method	**Specimen Id:**	**B1-01**	**B1-02**	**B1-03**	**B1-04**
AS1012.8.1 / AS1012.9	**Cap Type:**	Sulphur / Flyash	Sulphur / Flyash	Rubber	Rubber
	Diameter(mm):	100.0	100.2	100.0	100.0
	Height(mm):	199.0	199.0	200.0	198.0
	Height / Diameter Ratio:	1.99	1.99	2.00	1.98
	Date Tested:	26/08/2016	30/08/2016	06/09/2016	13/09/2016
	Age at Test(days):	3	7	14	21
	Moisture curing duration(days):	2	6	13	20
	Compressive Strength(MPa):	16.5	23.0	28.5	31.0
	Corr. Comp. Strength(MPa):	N/A	N/A	N/A	N/A
	Size of reinforcement (mm):	0	0	0	0
	Position (reinf.) from top (mm):	0.0	0.0	0.0	0.0
	Defect Clauses:	*	*	*	*
	Preconditioning (Wet/Dry):	Wet	Wet	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2350	2350	2340	2350
	Specimen Dimensions (mm):	100.0 x 199	100.2 x 199	100.0 x 200	100.0 x 198
	Density of Cap (t/m^3):	*	*	*	*
	Moisture Condition (At Test):	SSD	SSD	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No	No	No
	Slump(mm):	220	220	220	220
*	Air Content(%):	*	*	*	*
	Compaction Method:	*	*	*	*
	Number of Strokes or Insertions:	*	*	*	*

Report Comments:-

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Accredited for Compliance with ISO/IEC 17025

Accreditation Number: 2599

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Glenn Smith
A/Laboratory Manager
Date: 20/09/2016

Page 1 of 10

ROADS AND MARITIME SERVICES *Concrete*		Transport Roads & Maritime Services
CON Record No: 280	Client: Roads and Maritime Services - Robert Wiya Address: 90 Crown Street, Wollongong, NSW 2500	**Russell Vale Laboratory** 21 York Place Russell Vale NSW 2518 T: (02) 4222 3242 F: (02) 4222 3240 PO Box 62 Corrimal NSW 2518
Received: 23/08/2016	Client Ref: Lab Ref (Project):	
Sampled By: GS	Project Description: Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate.	
Sampling Method: AS1012.1 [7.2]	Work Details: Concrete Testing.	
Material: Concrete	Work Distance: *	*Laboratory Test Report*
Request Id:	Supplier:	Report: R00786 Part 01

	Sample Id:	**B1**	**B1**	**B2**	**B2**
	Date Sampled:	23/08/2016	23/08/2016	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*	*	*
	Lot Distance End(km):	*	*	*	*
	Batch Number:	Batch 1	Batch 1	Batch 2	Batch 2
	Sample Chainage (km) or Location:	RV Lab	RV Lab	RV Lab	RV Lab
	Sample Represents:	TRIAL 1	TRIAL 1	TRIAL 2	TRIAL 2
	Quantity Represented(m^3):	*	*	*	*
	Lane:	*	*	*	*
	Offset(m):	*	*	*	*
	Depth(mm):	* - *	* - *	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*	*	*
Test Method	**Specimen Id:**	**B1-05**	**B1-06**	**B2-12**	**B2-13**
AS1012.8.1 / AS1012.9	Cap Type:	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash
	Diameter(mm):	100.0	99.8	100.2	100.4
	Height(mm):	199.0	198.0	200.0	200.0
	Height / Diameter Ratio:	1.99	1.98	2.00	1.99
	Date Tested:	20/09/2016	20/09/2016	30/08/2016	06/09/2016
	Age at Test(days):	28	28	7	14
	Moisture curing duration(days):	27	27	6	13
	Compressive Strength(MPa):	34.0	34.0	24.5	32.0
	Corr. Comp. Strength(MPa):	N/A	N/A	N/A	N/A
	Size of reinforcement (mm):	0	0	0	0
	Position (reinf.) from top (mm):	0.0	0.0	0.0	0.0
	Defect Clauses:	*	*	*	*
	Preconditioning (Wet/Dry):	Wet	Wet	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2350	2350	2370	2380
	Specimen Dimensions (mm):	100.0 x 199	99.8 x 198	100.2 x 200	100.4 x 200
	Density of Cap (t/m^3):	*	*	*	*
	Moisture Condition (At Test):	SSD	SSD	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No	No	No
	Slump(mm):	220	220	75	75
*	Air Content(%):	*	*	*	*
	Compaction Method:	*	*	*	*
	Number of Strokes or Insertions:	*	*	*	*

ROADS AND MARITIME SERVICES		
Concrete		Transport Roads & Maritime Services
CON Record No: 280	Client: Roads and Maritime Services - Robert Wiya Address: 90 Crown Street, Wollongong, NSW 2500	**Russell Vale Laboratory** 21 York Place Russell Vale NSW 2518 T: (02) 4222 3242 F: (02) 4222 3240 PO Box 62 Corrimal NSW 2518
Received: 23/08/2016	Client Ref: Lab Ref (Project):	
Sampled By: GS	Project Description: Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate.	
Sampling Method: AS1012.1 [7.2]	Work Details: Concrete Testing.	
Material: Concrete	Work Distance: *	***Laboratory Test Report***
Request Id:	Supplier:	Report: **R00786** Part 01

	Sample Id:	B2	B2	B2	B3
	Date Sampled:	23/08/2016	23/08/2016	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*	*	*
	Lot Distance End(km):	*	*	*	*
	Batch Number:	Batch 2	Batch 2	Batch 2	Batch 3
	Sample Chainage (km) or Location:	RV Lab	RV Lab	RV Lab	RV Lab
	Sample Represents:	TRIAL 2	TRIAL 2	TRIAL 2	TRIAL 3
	Quantity Represented(m^3):	*	*	*	*
	Lane:	*	*	*	*
	Offset(m):	*	*	*	*
	Depth(mm):	* - *	* - *	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*	*	*
Test Method	**Specimen Id:**	**B2-14**	**B2-15**	**B2-16**	**B3-17**
AS1012.8.1 / AS1012.9	**Cap Type:**	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash
	Diameter(mm):	100.0	99.8	100.0	99.8
	Height(mm):	199.0	198.0	198.0	199.0
	Height / Diameter Ratio:	1.99	1.98	1.98	1.99
	Date Tested:	13/09/2016	20/09/2016	20/09/2016	30/08/2016
	Age at Test(days):	21	28	28	7
	Moisture curing duration(days):	20	27	27	6
	Compressive Strength(MPa):	33.0	34.5	35.5	21.5
	Corr. Comp. Strength(MPa):	N/A	N/A	N/A	N/A
	Size of reinforcement (mm):	0	0	0	0
	Position (reinf.) from top (mm):	0.0	0.0	0.0	0.0
	Defect Clauses:	*	*	*	*
	Preconditioning (Wet/Dry):	Wet	Wet	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2370	2370	2370	2370
	Specimen Dimensions (mm):	100.0 x 199	99.8 x 198	100.0 x 198	99.8 x 199
	Density of Cap (t/m^3):	*	*	*	*
	Moisture Condition (At Test):	SSD	SSD	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No	No	No
	Slump(mm):	75	75	75	90
*	Air Content(%):	*	*	*	*
	Compaction Method:	*	*	*	*
	Number of Strokes or Insertions:	*	*	*	*

ROADS AND MARITIME SERVICES

Concrete

NSW GOVERNMENT | Transport Roads & Maritime Services

Russell Vale Laboratory
21 York Place
Russell Vale NSW 2518
T: (02) 4222 3242
F: (02) 4222 3240
PO Box 62 Corrimal NSW 2518

Laboratory Test Report

Report: **R00786** Part 01

CON Record No:	280
Received:	23/08/2016
Sampled By:	GS
Sampling Method:	AS1012.1 [7.2]
Material:	Concrete
Request Id:	
Client:	Roads and Maritime Services - Robert Wiya
Address:	90 Crown Street, Wollongong, NSW 2500
Client Ref:	
Lab Ref (Project):	
Project Description:	Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate.
Work Details:	Concrete Testing.
Work Distance:	*
Supplier:	

Test Method	Sample Id:	B3	B3	B3	B3
	Date Sampled:	23/08/2016	23/08/2016	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*	*	*
	Lot Distance End(km):	*	*	*	*
	Batch Number:	Batch 3	Batch 3	Batch 3	Batch 3
	Sample Chainage (km) or Location:	RV Lab	RV Lab	RV Lab	RV Lab
	Sample Represents:	TRIAL 3	TRIAL 3	TRIAL 3	TRIAL 3
	Quantity Represented(m^3):	*	*	*	*
	Lane:	*	*	*	*
	Offset(m):	*	*	*	*
	Depth(mm):	* - *	* - *	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*	*	*
Test Method	**Specimen Id:**	**B3-18**	**B3-19**	**B3-20**	**B3-21**
AS1012.8.1 / AS1012.9	Cap Type:	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash
	Diameter(mm):	100.2	100.2	100.2	100.0
	Height(mm):	200.0	199.0	199.0	199.0
	Height / Diameter Ratio:	2.00	1.99	1.99	1.99
	Date Tested:	06/09/2016	13/09/2016	20/09/2016	20/09/2016
	Age at Test(days):	14	21	28	28
	Moisture curing duration(days):	13	20	27	27
	Compressive Strength(MPa):	25.0	27.0	28.5	27.5
	Corr. Comp. Strength(MPa):	N/A	N/A	N/A	N/A
	Size of reinforcement (mm):	0	0	0	0
	Position (reinf.) from top (mm):	0.0	0.0	0.0	0.0
	Defect Clauses:	*	*	*	*
	Preconditioning (Wet/Dry):	Wet	Wet	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2380	2380	2370	2370
	Specimen Dimensions (mm):	100.2 x 200	100.2 x 199	100.2 x 199	100.0 x 199
	Density of Cap (t/m^3):	*	*	*	*
	Moisture Condition (At Test):	SSD	SSD	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No	No	No
	Slump(mm):	90	90	90	90
*	Air Content(%):	*	*	*	*
	Compaction Method:	*	*	*	*
	Number of Strokes or Insertions:	*	*	*	*

ROADS AND MARITIME SERVICES *Concrete*		Transport Roads & Maritime Services
CON Record No: 280	Client: Roads and Maritime Services - Robert Wiya Address: 90 Crown Street, Wollongong, NSW 2500	**Russell Vale Laboratory** 21 York Place Russell Vale NSW 2518 T: (02) 4222 3242 F: (02) 4222 3240 PO Box 62 Corrimal NSW 2518
Received: 23/08/2016	Client Ref: Lab Ref (Project):	
Sampled By: GS	Project Description: Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate.	
Sampling Method: AS1012.1 [7.2]	Work Details: Concrete Testing.	
Material: Concrete	Work Distance: *	***Laboratory Test Report***
Request Id:	Supplier:	Report: **R00786** Part 01

	Sample Id:	**B4**	**B4**	**B4**	**B4**
	Date Sampled:	23/08/2016	23/08/2016	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*	*	*
	Lot Distance End(km):	*	*	*	*
	Batch Number:	Batch 4	Batch 4	Batch 4	Batch 4
	Sample Chainage (km) or Location:	RV Lab	RV Lab	RV Lab	RV Lab
	Sample Represents:	TRIAL 4	TRIAL 4	TRIAL 4	TRIAL 4
	Quantity Represented(m^3):	*	*	*	*
	Lane:	*	*	*	*
	Offset(m):	*	*	*	*
	Depth(mm):	* - *	* - *	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*	*	*
Test Method	**Specimen Id:**	**B4-22**	**B4-23**	**B4-24**	**B4-25**
AS1012.8.1 / AS1012.9	**Cap Type:**	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash
	Diameter(mm):	100.0	99.8	100.2	100.2
	Height(mm):	199.0	198.0	199.0	198.0
	Height / Diameter Ratio:	1.99	1.98	1.99	1.98
	Date Tested:	26/08/2016	30/08/2016	06/09/2016	13/09/2016
	Age at Test(days):	3	7	14	21
	Moisture curing duration(days):	2	6	13	20
	Compressive Strength(MPa):	16.0	20.0	23.5	24.0
	Corr. Comp. Strength(MPa):	N/A	N/A	N/A	N/A
	Size of reinforcement (mm):	0	0	0	0
	Position (reinf.) from top (mm):	0.0	0.0	0.0	0.0
	Defect Clauses:	*	*	*	*
	Preconditioning (Wet/Dry):	Wet	Wet	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2360	2370	2370	2360
	Specimen Dimensions (mm):	100.0 x 199	99.8 x 198	100.2 x 199	100.2 x 198
	Density of Cap (t/m^3):	*	*	*	*
	Moisture Condition (At Test):	SSD	SSD	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No	No	No
	Slump(mm):	95	95	95	95
*	Air Content(%):	*	*	*	*
	Compaction Method:	*	*	*	*
	Number of Strokes or Insertions:	*	*	*	*

ROADS AND MARITIME SERVICES

Concrete

Transport Roads & Maritime Services
Russell Vale Laboratory
21 York Place
Russell Vale NSW 2518
T: (02) 4222 3242
F: (02) 4222 3240
PO Box 62 Corrimal NSW 2518

Laboratory Test Report

Report: **R00786** Part 01

CON Record No:	280
Received:	23/08/2016
Sampled By:	GS
Sampling Method:	AS1012.1 [7.2]
Material:	Concrete
Request Id:	
Client:	Roads and Maritime Services - Robert Wiya
Address:	90 Crown Street, Wollongong, NSW 2500
Client Ref:	
Lab Ref (Project):	
Project Description:	Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate.
Work Details:	Concrete Testing.
Work Distance:	*
Supplier:	

Test Method	Sample Id:	B4	B4	B5	B5
	Date Sampled:	23/08/2016	23/08/2016	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*	*	*
	Lot Distance End(km):	*	*	*	*
	Batch Number:	Batch 4	Batch 4	Batch 5	Batch 5
	Sample Chainage (km) or Location:	RV Lab	RV Lab	RV Lab	RV Lab
	Sample Represents:	TRIAL 4	TRIAL 4	TRIAL 5	TRIAL 5
	Quantity Represented(m^3):	*	*	*	*
	Lane:	*	*	*	*
	Offset(m):	*	*	*	*
	Depth(mm):	* - *	* - *	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*	*	*
Test Method	**Specimen Id:**	**B4-26**	**B4-27**	**B5-33**	**B5-34**
AS1012.8.1 / AS1012.9	**Cap Type:**	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash
	Diameter(mm):	100.0	100.0	100.0	100.4
	Height(mm):	198.0	198.0	199.0	199.0
	Height / Diameter Ratio:	1.98	1.98	1.99	1.98
	Date Tested:	20/09/2016	20/09/2016	30/08/2016	06/09/2016
	Age at Test(days):	28	28	7	14
	Moisture curing duration(days):	27	27	6	13
	Compressive Strength(MPa):	25.5	24.5	20.5	22.5
	Corr. Comp. Strength(MPa):	N/A	N/A	N/A	N/A
	Size of reinforcement (mm):	0	0	0	0
	Position (reinf.) from top (mm):	0.0	0.0	0.0	0.0
	Defect Clauses:	*	*	*	*
	Preconditioning (Wet/Dry):	Wet	Wet	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2360	2370	2390	2380
	Specimen Dimensions (mm):	100.0 x 198	100.0 x 198	100.0 x 199	100.4 x 199
	Density of Cap (t/m^3):	*	*	*	*
	Moisture Condition (At Test):	SSD	SSD	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No	No	No
	Slump(mm):	95	95	65	65
*	Air Content(%):	*	*	*	*
	Compaction Method:	*	*	*	*
	Number of Strokes or Insertions:	*	*	*	*

ROADS AND MARITIME SERVICES *Concrete*		Transport Roads & Maritime Services **Russell Vale Laboratory** 21 York Place Russell Vale NSW 2518 T: (02) 4222 3242 F: (02) 4222 3240 PO Box 62 Corrimal NSW 2518
CON Record No: 280	Client: Roads and Maritime Services - Robert Wiya Address: 90 Crown Street, Wollongong, NSW 2500	
Received: 23/08/2016	Client Ref: Lab Ref (Project):	
Sampled By: GS	Project Description: Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate.	
Sampling Method: AS1012.1 [7.2]	Work Details: Concrete Testing.	
Material: Concrete	Work Distance: *	***Laboratory Test Report***
Request Id:	Supplier:	Report: **R00786** Part 01

	Sample Id:	**B5**	**B5**	**B5**	**B6**
	Date Sampled:	23/08/2016	23/08/2016	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*	*	*
	Lot Distance End(km):	*	*	*	*
	Batch Number:	Batch 5	Batch 5	Batch 5	Batch 6
	Sample Chainage (km) or Location:	RV Lab	RV Lab	RV Lab	RV Lab
	Sample Represents:	TRIAL 5	TRIAL 5	TRIAL 5	TRIAL 6
	Quantity Represented(m^3):	*	*	*	*
	Lane:	*	*	*	*
	Offset(m):	*	*	*	*
	Depth(mm):	* - *	* - *	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*	*	*
Test Method	**Specimen Id:**	**B5-35**	**B5-36**	**B5-37**	**B6-38**
AS1012.8.1 / AS1012.9	**Cap Type:**	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash
	Diameter(mm):	100.0	100.0	100.0	100.4
	Height(mm):	198.0	198.0	198.0	198.0
	Height / Diameter Ratio:	1.98	1.98	1.98	1.97
	Date Tested:	13/09/2016	20/09/2016	20/09/2016	26/08/2016
	Age at Test(days):	21	28	28	3
	Moisture curing duration(days):	20	27	27	2
	Compressive Strength(MPa):	23.5	24.0	24.5	15.0
	Corr. Comp. Strength(MPa):	N/A	N/A	N/A	N/A
	Size of reinforcement (mm):	0	0	0	0
	Position (reinf.) from top (mm):	0.0	0.0	0.0	0.0
	Defect Clauses:	*	*	*	*
	Preconditioning (Wet/Dry):	Wet	Wet	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2380	2390	2380	2380
	Specimen Dimensions (mm):	100.0 x 198	100.0 x 198	100.0 x 198	100.4 x 198
	Density of Cap (t/m^3):	*	*	*	*
	Moisture Condition (At Test):	SSD	SSD	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No	No	No
	Slump(mm):	65	65	65	100
*	Air Content(%):	*	*	*	*
	Compaction Method:	*	*	*	*
	Number of Strokes or Insertions:	*	*	*	*

ROADS AND MARITIME SERVICES *Concrete*		Transport Roads & Maritime Services
CON Record No: 280 Received: 23/08/2016 Sampled By: GS Sampling Method: AS1012.1 [7.2] Material: Concrete Request Id:	Client: Roads and Maritime Services - Robert Wiya Address: 90 Crown Street, Wollongong, NSW 2500 Client Ref: Lab Ref (Project): Project Description: Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate. Work Details: Concrete Testing. Work Distance: * Supplier:	**Russell Vale Laboratory** 21 York Place Russell Vale NSW 2518 T: (02) 4222 3242 F: (02) 4222 3240 PO Box 62 Corrimal NSW 2518 ***Laboratory Test Report*** Report: **R00786** Part 01

	Sample Id:	**B6**	**B6**	**B6**	**B6**
	Date Sampled:	23/08/2016	23/08/2016	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*	*	*
	Lot Distance End(km):	*	*	*	*
	Batch Number:	Batch 6	Batch 6	Batch 6	Batch 6
	Sample Chainage (km) or Location:	RV Lab	RV Lab	RV Lab	RV Lab
	Sample Represents:	TRIAL 6	TRIAL 6	TRIAL 6	TRIAL 6
	Quantity Represented(m^3):	*	*	*	*
	Lane:	*	*	*	*
	Offset(m):	*	*	*	*
	Depth(mm):	* - *	* - *	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*	*	*
Test Method	**Specimen Id:**	**B6-39**	**B6-40**	**B6-41**	**B6-42**
AS1012.8.1 / AS1012.9	**Cap Type:**	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash
	Diameter(mm):	100.0	100.2	100.0	100.2
	Height(mm):	200.0	197.0	198.0	199.0
	Height / Diameter Ratio:	2.00	1.97	1.98	1.99
	Date Tested:	30/08/2016	06/09/2016	13/09/2016	20/09/2016
	Age at Test(days):	7	14	21	28
	Moisture curing duration(days):	6	13	20	27
	Compressive Strength(MPa):	19.0	20.5	21.0	21.5
	Corr. Comp. Strength(MPa):	N/A	N/A	N/A	N/A
	Size of reinforcement (mm):	0	0	0	0
	Position (reinf.) from top (mm):	0.0	0.0	0.0	0.0
	Defect Clauses:	*	*	*	*
	Preconditioning (Wet/Dry):	Wet	Wet	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2390	2370	2360	2370
	Specimen Dimensions (mm):	100.0 x 200	100.2 x 197	100.0 x 198	100.2 x 199
	Density of Cap (t/m^3):	*	*	*	*
	Moisture Condition (At Test):	SSD	SSD	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No	No	No
	Slump(mm):	100	100	100	100
*	Air Content(%):	*	*	*	*
	Compaction Method:	*	*	*	*
	Number of Strokes or Insertions:	*	*	*	*

ROADS AND MARITIME SERVICES *Concrete*		NSW Transport Roads & Maritime Services
CON Record No: 280 Received: 23/08/2016 Sampled By: GS Sampling Method: AS1012.1 [7.2] Material: Concrete Request Id:	Client: Roads and Maritime Services - Robert Wiya Address: 90 Crown Street, Wollongong, NSW 2500 Client Ref: Lab Ref (Project): Project Description: Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate. Work Details: Concrete Testing. Work Distance: * Supplier:	**Russell Vale Laboratory** 21 York Place Russell Vale NSW 2518 T: (02) 4222 3242 F: (02) 4222 3240 PO Box 62 Corrimal NSW 2518 ***Laboratory Test Report*** Report: **R00786** Part 01

	Sample Id:	**B6**	**B7**	**B7**	**B7**
	Date Sampled:	23/08/2016	23/08/2016	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*	*	*
	Lot Distance End(km):	*	*	*	*
	Batch Number:	Batch 6	Batch 7	Batch 7	Batch 7
	Sample Chainage (km) or Location:	RV Lab	RV Lab	RV Lab	RV Lab
	Sample Represents:	TRIAL 6	TRIAL 7	TRIAL 7	TRIAL 7
	Quantity Represented(m^3):	*	*	*	*
	Lane:	*	*	*	*
	Offset(m):	*	*	*	*
	Depth(mm):	* - *	* - *	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*	*	*
Test Method	**Specimen Id:**	**B6-43**	**B7-49**	**B7-50**	**B7-51**
AS1012.8.1 / AS1012.9	Cap Type:	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash	Sulphur / Flyash
	Diameter(mm):	100.2	100.0	100.0	100.0
	Height(mm):	199.0	200.0	200.0	200.0
	Height / Diameter Ratio:	1.99	2.00	2.00	2.00
	Date Tested:	20/09/2016	30/08/2016	06/09/2016	13/09/2016
	Age at Test(days):	28	7	14	21
	Moisture curing duration(days):	27	6	13	20
	Compressive Strength(MPa):	22.0	28.5	33.5	36.5
	Corr. Comp. Strength(MPa):	N/A	N/A	N/A	N/A
	Size of reinforcement (mm):	0	0	0	0
	Position (reinf.) from top (mm):	0.0	0.0	0.0	0.0
	Defect Clauses:	*	*	*	*
	Preconditioning (Wet/Dry):	Wet	Wet	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2380	2380	2390	2380
	Specimen Dimensions (mm):	100.2 x 199	100.0 x 200	100.0 x 200	100.0 x 200
	Density of Cap (t/m^3):	*	*	*	*
	Moisture Condition (At Test):	SSD	SSD	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No	No	No
	Slump(mm):	100	90	90	90
*	Air Content(%):	*	*	*	*
	Compaction Method:	*	*	*	*
	Number of Strokes or Insertions:	*	*	*	*

ROADS AND MARITIME SERVICES *Concrete*		Transport Roads & Maritime Services
CON Record No: 280 Received: 23/08/2016 Sampled By: GS Sampling Method: AS1012.1 [7.2] Material: Concrete Request Id:	Client: Roads and Maritime Services - Robert Wiya Address: 90 Crown Street, Wollongong, NSW 2500 Client Ref: Lab Ref (Project): Project Description: Assessment of Compressive Strength on Concrete Trial Mixes using RAP Aggregate. Work Details: Concrete Testing. Work Distance: * Supplier:	**Russell Vale Laboratory** 21 York Place Russell Vale NSW 2518 T: (02) 4222 3242 F: (02) 4222 3240 PO Box 62 Corrimal NSW 2518 ***Laboratory Test Report*** Report: **R00786** Part 01

	Sample Id:	**B7**	**B7**
	Date Sampled:	23/08/2016	23/08/2016
	Lot Distance Start(km):	*	*
	Lot Distance End(km):	*	*
	Batch Number:	Batch 7	Batch 7
	Sample Chainage (km) or Location:	RV Lab	RV Lab
	Sample Represents:	TRIAL 7	TRIAL 7
	Quantity Represented(m^3):	*	*
	Lane:	*	*
	Offset(m):	*	*
	Depth(mm):	* - *	* - *
	Specimen Description:	Conc Cyl	Conc Cyl
	Nominal Size(mm):	20	20
	Specified Compressive Strength(MPa):	25 at 28 Days	25 at 28 Days
	Time between moulding and start of standard curing: (Hrs)	24	24
	Daily ambient min/max temperature (if >36hrs) (°C)	*	*
Test Method	**Specimen Id:**	**B7-52**	**B7-53**
AS1012.8.1 / AS1012.9	**Cap Type:**	Sulphur / Flyash	Sulphur / Flyash
	Diameter(mm):	100.0	100.2
	Height(mm):	200.0	200.0
	Height / Diameter Ratio:	2.00	2.00
	Date Tested:	20/09/2016	20/09/2016
	Age at Test(days):	28	28
	Moisture curing duration(days):	27	27
	Compressive Strength(MPa):	37.5	37.5
	Corr. Comp. Strength(MPa):	N/A	N/A
	Size of reinforcement (mm):	0	0
	Position (reinf.) from top (mm):	0.0	0.0
	Defect Clauses:	*	*
	Preconditioning (Wet/Dry):	Wet	Wet
AS1012.12.2	Mass per Unit Volume(kg/m^3):	2380	2390
	Specimen Dimensions (mm):	100.0 x 200	100.2 x 200
	Density of Cap (t/m^3):	*	*
	Moisture Condition (At Test):	SSD	SSD
AS1012.3.1	Lateral Shear or Collapse:	No	No
	Slump(mm):	90	90
*	Air Content(%):	*	*
	Compaction Method:	*	*
	Number of Strokes or Insertions:	*	*

15 APPENDIX H MODULUS OF ELASTICITY RESULTS

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CONCRETE TEST REPORT

CLIENT: **ROAD AND MARITIME SERVICES (Russell Vale)** **FILE No: 65 / 16**

PROJECT: Concrete Trials with RAP – Lab. Number R00786 **Request No: 69515**

Lab. Sample No: 182947

SAMPLE DESCRIPTION: **100x200mm concrete cylinders**

TEST METHOD: AS1012.17 – STATIC CHORD MODULUS OF ELASTICITY
METHOD 1 – Based on the measured compressive strength of the concrete

Cast Date: 23.08.2016
Date of Test: 20.09.2016
Age at date of Test: 28 days
Ambient Temperature: 21°C
Ambient R.H: 52%

SPECIMEN NO:	MOD OF ELASTICITY (GPa)	POISSON'S RATIO
B1 - 9	24.6	0.153
B1 - 10	23.0	0.159
B1 - 11	23.7	0.150

Measured average compressive strength: 34.0 MPa
Average static chord modulus of elasticity: 24.7 GPa
Average POISSON'S RATIO: 0.154

Remarks: Specimens prepared by the client and delivered to this Laboratory on **16.09.2016 in wet condition**. Subsequent curing and testing was in accordance with AS1012.8 and AS1012.17.

Glenn Smith, File 7633, Ref: 69515RC

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Approved Signatory ______ Arnel Santos

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CONCRETE TEST REPORT

CLIENT: ROAD AND MARITIME SERVICES (Russell Vale) **FILE No: 65 / 16**

PROJECT: Concrete Trials with RAP – Lab. Number R00786 **Request No: 69515**

Lab. Sample No: 182948

SAMPLE DESCRIPTION: **100x200mm concrete cylinders**

TEST METHOD: AS1012.17 – STATIC CHORD MODULUS OF ELASTICITY

METHOD 1 – Based on the measured compressive strength of the concrete

Cast Date: 23.08.2016
Date of Test: 20.09.2016
Age at date of Test: 28 days
Ambient Temperature: 21°C
Ambient R.H: 52%

SPECIMEN NO:	MOD OF ELASTICITY (GPa)	POISSON'S RATIO
B4 - 30	19.2	0.144
B4 - 31	19.1	0.142
B4 - 32	20.0	0.140

Measured average compressive strength: 25.5 MPa
Average static chord modulus of elasticity: 19.6 GPa
Average POISSON'S RATIO: 0.142

Remarks: Specimens prepared by the client and delivered to this Laboratory on **16.09.2016 in wet condition**. Subsequent curing and testing was in accordance with AS1012.8 and AS1012.17.

Glenn Smith, File 7633, Ref: 69515RC

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Approved Signatory Amel Santos

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CONCRETE TEST REPORT

CLIENT: ROAD AND MARITIME SERVICES (Russell Vale) **FILE No: 65 / 16**

PROJECT: Concrete Trials with RAP – Lab. Number R00786 **Request No: 69515**

Lab. Sample No: 182949

SAMPLE DESCRIPTION: **100x200mm concrete cylinders**

TEST METHOD: AS1012.17 – STATIC CHORD MODULUS OF ELASTICITY

METHOD 1 – Based on the measured compressive strength of the concrete

Cast Date: 23.08.2016
Date of Test: 20.09.2016
Age at date of Test: 28 days
Ambient Temperature: 21°C
Ambient R.H: 52%

SPECIMEN NO:	MOD OF ELASTICITY (GPa)	POISSON'S RATIO
B6 - 46	17.5	0.143
B6 - 47	17.3	0.142
B6 - 48	16.7	0.138

Measured average compressive strength: 17.2 MPa
Average static chord modulus of elasticity: 19.6 GPa
Average POISSON'S RATIO: 0.141

Remarks: Specimens prepared by the client and delivered to this Laboratory on **16.09.2016 in wet condition**. Subsequent curing and testing was in accordance with AS1012.8 and AS1012.17.

Glenn Smith, File 7633, Ref: 69515RC

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Approved Signatory [signature] Arnel Santos
Date 22.09.2016 Serial No. 150145

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