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Classification and Characterization of Recycled Construction Aggregate (RCA)

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Abstract

Construction projects use up large quantities of natural resources and produce tonnes of construction and demolition waste (CDW). Because of its growth, these quantities have increased in the last few years and it has now become necessary to create a sustainable method of development in civil construction. Therefore, recycling and utilization of recycled materials in construction projects can be the most promising solution for this problem. Due to important role and high portion of aggregates in asphalt concrete, utilization of recycled materials including recycled construction aggregates (RCA) can provide enormous benefits from the viewpoint of environmental sustainability and effective use of resources. In spite of the awareness of the importance of using RCA and much research being conducted, there is still a need for a deeper study about the characteristics of the RCA. The variability in behaviour and performance of RCA used in construction projects indicates the variability in their composition. This paper presents the results of a statistical study, image analysis and experimental study to evaluate the characteristics of RCA as an alternative for virgin aggregate in asphalt mixture. A series of characterization tests were conducted three times, using RCA collected at different dates.

***Keywords*:** Asphalt, Igneous, Metamorphic, Recycled construction aggregate, Sedimentary

1. INTRODUCTION

The need for sustainable asphalt design and construction is becoming a priority within the asphalt industry. On the other hand, the large amount of construction and demolition waste generation around the world justifies the idea of using recycled construction aggregate (RCA) in new asphalt mixtures. RCA offers a good solution to design a sustainable asphalt mixture not only due to large amount of construction and demolition wastes but also providing a sound level of function for wearing course, because RCA is made up of three different aggregate types. However, it is important to understand the performance characteristics of RCA when specifying it for partial replacement of natural aggregates, since the overall performance and durability of the construction needs to be maintained. In addition, the level of RCA substitution achievable will depend upon the properties of the recycled aggregate, its availability in the market, the performance criteria of the mix, the whole-of-life sustainability of the product and the economic viability of its inclusion. This paper covers some RCA characteristics and the specifications of RCA required for producing sustainable asphalt with high standard.

1.1. Demand for aggregates and public infrastructure

Asphalt plays a vital role in global transportation infrastructure and drives economic growth and social well-being in developed as well as developing countries (Mangum, 2006). Asphalt contains approximately 95% aggregate and 5% bitumen. Referring to Ektas and Karacasu (2012), a layer of 15 cm thick and 10 m wide for one kilometre of road requires almost 3,750 tonnes of mixture containing aggregate and bitumen. In 2007, the latest year for which figures are available, about 1.6 trillion metric tonnes of asphalt were produced worldwide (EAPA & NAPA, 2009). Considering the important role and high proportion of aggregates in asphalt mixtures, it can be estimated that the large quantities of aggregates are required for road construction. Referring to the previous discussions and considering above mentioned statistics, application of waste materials in road construction, including the asphalt surface layer remains an attractive route to solve the problems associated with natural resource depletion and solid waste disposal. However, physicochemical and mechanical properties of recycled materials inevitably hinder the beneficial use of such materials in pavement construction, and particularly in asphalt mixtures because the application of waste materials should not influence the structural and functional aspects of the surface (wearing) course.

In general, the desired surface (wearing) course requires two major characteristics:

- Good Resistance to shear forces which depends on the bitumen quality and the aggregate skeleton of the asphalt mixture. In this regard, particle shape substantially affects interparticle friction and coarse aggregate shear resistance (White et al., 2016).
- Good Skid Resistance which depends on the microstructure and macrostructure of a pavement surface (Haas et al., 1994).

Therefore, the ability to design an adequate asphalt mix incorporating appropriate waste materials becomes a key issue in the design and construction of pavements, including surface course, in line with sustainable development concept.

1.2. Cost of aggregates for public infrastructure

Referring to the report by Macromonitor (2013) regarding the cost analysis of infrastructure construction in Victoria, the single biggest cost component in an infrastructure construction is materials. The Victorian example is an indicative of the cost of infrastructure throughout the world and it means that the cost of meeting future demand for public infrastructure will increase and that supplying construction materials to meet this demand will have a significant impact on this cost increase. It should be mentioned that to meet future demands for affordable public infrastructure, there must be efficient supply of construction materials. The efficiency of the construction materials supply is largely determined by location, as transportation equates to approximately 20 to 25% of the total cost of materials. This means that transportation costs have a significant impact on total construction cost. For example, according to a report from Access Economics (2006), in Melbourne, which has many quarries located in the metropolitan area and the average transport distance from quarry to asphalt plant is 30 km, the delivery cost of material is 70% less than Sydney in which there is one remaining metropolitan quarry, and the average transportation distance is 60 km (Access Economics, 2006). Therefore, it is essential to recognize the importance of locally supplied construction materials to the provision of affordable public infrastructure to ensure affordable supply. In addition, the identification of new and innovative resources of construction materials (like recycled aggregates) is of high importance in this regard.

2. A REVIEW ON RCA IN AUSTRALIA

As Australia's population grows, there will be an increasing demand for public infrastructure and construction materials. Today, the demand for aggregate materials is much greater than what could possibly be supplied using virgin aggregates alone. The Australian Quarrying Industry Estimates average consumption of aggregates across Australia at around 7 tonnes per person per annum.

The construction and demolition sector is Australia's biggest generator of waste who is responsible for around 40% of all Australian waste material with 19 million tonnes of annual waste by-products associated with our construction and demolition activities (CCAA, 2008a). If all the materials generated during Australian construction and demolition projects were treated as 'waste', it would keep at least 30 major landfill facilities operating all year round (Australia's Sustainable Aggregate Industry, 2013).

In Australia, RCA has been the most common construction and demolition waste used in construction projects as coarse and fine aggregates. RCA is available in Australian markets principally in Sydney and Melbourne. Figure 1 illustrates the sources of RCA in Australia, noting that Man Sand stands for "manufactured sand".

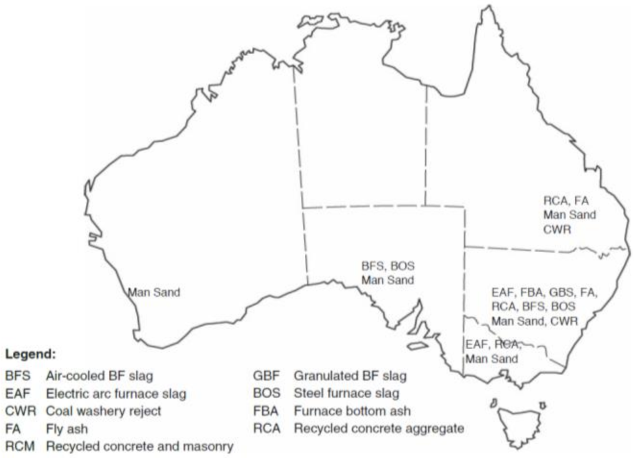

Figure 1. Sources of RCA in Australia (CCAA, 2008b)

Based on a life cycle analysis undertaken by the RMIT University, sustainable aggregates made from RCA have a 65% lower greenhouse emissions impact than similar products made from virgin rocks across the full product life cycle, largely due to avoiding the energy needed to quarry rock. Therefore, it will undoubtedly be required that a mixture of virgin and recycled materials be used, depending on the required performance and the relative availability of different materials.

2.1. Geological Study on RCA

The asphalt mixture performance can vary significantly depending on the type, percentages, and the properties of the materials. When it comes to aggregates, the physical, mechanical and chemical properties of the aggregates, resulting from the geological origin and mineralogy of the potential source and its subsequent weathering or alteration, play an important role on final product performance.

Aggregates can be classified in three groups reflecting the origin, formation and history of their rock:

- Igneous rocks which are generally of high strength.
- Sedimentary rocks constitute the greatest variation in strength and behaviour.
- Metamorphic rocks show a great variety in structure and composition and properties. Strength and resistance to weathering of metamorphic rocks make them suitable for use in construction projects.

Study on properties of all these rock groups indicates that each geological group has its own advantages and disadvantages in terms of engineering properties.

RCA is made up of these three different aggregate types in terms of geological classification, and hence can provide proper level of function for asphalt surface layer. For example, a matrix of portland cement concrete which will vary between basalt (i.e. Basic Igneous) and granite (i.e. Acidic Igneous) depending on the source of material and the age of the building from which it came, will form the igneous part of RCA. Sandstone or an agglomerate of sand and cement paste involves the sedimentary part of RCA, and metamorphic part of RCA could be quartz or hornfels depending on the source rock in the concrete, or could be "man-made" metamorphic rock such as ceramic, glass or brick.

As each of the aggregate types (i.e. igneous, sedimentary, and metamorphic) has different properties, their proportion in RCA significantly affects the properties of RCA, and subsequently the final performance of asphalt mixture. For instance, the aggregate proportion influences the bitumen absorption of asphalt mixtures. If RCA contains a lot of sedimentary rock, the RCA would be too absorbent and the binder content will be reduced by absorption. Consequently, the asphalt will be too dry and crack and ravel. In contrast, if the RCA contains a very large proportion of basalts and metamorphic group such as glass and ceramics, it would be very low in absorption, and subsequently the mix will be wet and lack shear strength and shove. It should be mentioned that crushed brick could be low or high in absorption depending on the amount of firing (clinker or callow).
Moreover, the skid resistance will be impacted by the aggregate composition. Asphalt concrete with crushed brick will provide differential wearing of the asphalt by creating a fresh and rugose surface and subsequently will enhance skid resistance (Chen and Liao, 2002). Therefore, RCA will positively affect the skid resistance of the asphalt concrete, as:

- Both the Igneous and Metamorphic groups will be generally hard and prone to polishing,
- The Sedimentary group and crushed brick will wear differentially and create an ever changing depth.

In light of this, asphalt surface layers provide unique opportunities for RCA reuse, as using RCA in asphalt surface layer can contribute to improvement of engineering characteristics of the asphalt pavement materials as well as the pavement performance, representing a value application for RCA. However, significant developmental limitations and many relevant considerations must be addressed in this regard.

2.2. Statistical study on RCA in Sydney

In spite of the awareness of the importance of using RCA and much research being conducted, there is still a need for a deeper study of the characteristics of RCA. The variability in the behaviour and performance of RCA used in different construction projects indicates the variability in RCA composition. Therefore, this research investigates the composition and variability of recycled construction aggregates through classification of aggregate samples collected from a recycling centre in Sydney. For this purpose, the RCA is collected at different dates over one year, and is categorized into different geological groups of igneous, metamorphic, and sedimentary, respectively (from left to right), as illustrated in Figure 2.

Figure 2: Classification of Recycled Construction Aggregate (RCA)

It is intended to create a database containing the composition and characteristics of RCA produced in Sydney in twelve months. The results of sorting RCA samples into different geological groups are presented in Table 1. As the results of classification shows, the sedimentary rocks in RCA are the greatest part and significantly influence the RCA properties. However, the man made metamorphic rocks such as bricks and ceramics involve about 20% of RCA. These types of man made aggregates can enhance both the strength (due to a good shape) and the durability due to low absorption as well as skid resistance.

Table 1. Summary of Statistical Study on the Classification of RCA

Average Percentage of Aggregate in the Sample	Aggregate Type		
	Igneous	**Sedimentary**	**Metamorphic**
	17	64	19

In an investigation by Yeaman (1976), it has been shown that the addition of small quantities of crushed brick to asphalt mixture, improves the skid resistance of this material (Yeaman, 1976). Therefore, the variability in RCA composition can result in making a superior hot mix asphalt (HMA) to Natural aggregate mixtures.

2.3. Study of RCA Characteristics

As discussed previously, the surface (wearing) course requires two major characteristics:

- Good Resistance to shear forces
- Adequate skid resistance

Aggregates with good particle shape will increase the wearing course resistance to shear forces (Mohajerani, 1997). In addition, the skid resistance is related to microstructure and macrostructure of aggregates. Microtexture is mainly dependent on aggregate shape characteristics and mineralogy, whereas; macrotexture is a function of mix properties, compaction method, and aggregate gradation (AASHTO, 1976). In this study, the particle shape of RCA is evaluated through the most commonly used tests including Particle Shape Test (AS 1141.14, 2007) and Flakiness Index test (AS 1141.15, 1999). The results of these tests on RCA and basalt are given in Table 2. As presented in Table 2, basalt materials show more of misshapen particles than RCA while still below the 35% limit of the Australian standard. Also, the results of flakiness index test show that RCA has less flakiness index than basalt which can positively affect the inter-particle interlock in asphalt mixture. This can subsequently lead to improvement in shear resistance of asphalt mix containing RCA.

Table 2: The Results of Particle Shape and Flakiness Index Test for RCA and Basalt and Australian Standard Limits for Dense Graded Asphalt

Test Name	Test Method	Aggregates		Australian Standards Limit (%)
		RCA	**Basalt**	
Particle Shape Test	AS 1141.14	6.2	18.3	35% (max)
Flakiness Index Test	AS 1141.15	6.9	19	25% (max)

Table 3: The Results of Particle Density and Water Absorption Test on RCA and Australian Standards Limit for Dense Graded Asphalt

Property	RCA	Sedimentary Rock in RCA	Igneous Rock in RCA	Metamorphic Rock in RCA	Basalt	Standards Limits
Water Absorption	6.30	7.64	2.03	5.86	1.64	2 % (max) heavy/ very heavy traffic
Particle Density	2.570	2.464	2.675	2.588	2.640	-

In addition, as mentioned previously, RCA is made up of different aggregates. Each of the aggregates will have different properties of which the most important is porosity that affects the absorption. The absorption is an indication of porosity in aggregate which demonstrates the pore structure of the aggregate. In asphalt mixtures, a porous aggregate increases the binder absorption, resulting in a dry and less cohesive asphalt mixture. Therefore, the determination of water absorption of individual groups of aggregates in RCA as well as RCA itself is of high importance when studying the RCA characteristics. To this end, water absorption and particle density test is considered as part of this research in order to obtain detailed information and data on this key property of RCA. The water absorption and particle density test is performed based on the procedure described in AS 1141.6.1 (2000), and the test results are presented in Table 3. The results of particle density and water absorption test on different rocks (i.e. igneous, sedimentary and metamorphic), as presented in Table 3, indicate the high absorption of sedimentary and metamorphic rocks in comparison with igneous rock. As can be observed, the RCA water absorption exceeds the limit set by the Australian Standard, mostly due to high proportion of sedimentary rocks in RCA.

3. CONCLUSION

From the study, it was determined that there are approximately 2,200 quarries operating across Australia that produce annually some 130 million tonnes of aggregates to be used in construction projects. If the current consumption rates are maintained, then the Australian industry will need to consider a 60% increase in production by 2050. On the other hand, construction projects produce large quantities of construction and demolition waste (CDW) including RCA. Even though there are many CDW management approaches to reduce the quantity of the generated CDW, it is impossible to stop its production. Therefore, a number of industry and academically based research projects have been undertaken to ascertain performance limits for recycled aggregates including RCA. However, the variability in RCA composition has led to the variability in the results of behaviour and performance of RCA used in construction projects. Therefore, the main aim of this research was to provide more insight into the contribution of aggregate types (i.e. igneous, sedimentary, and metamorphic) as different components of RCA as well as to create a data base containing the characteristics of RCA produced in nearest recycling units, over twelve months, that can be used in future research using RCA.

To this end, a series of characterisation tests have been conducted on different aggregate types of RCA samples collected at different dates over a twelve month period. The results of RCA classification reveals that RCA is composed of mostly sedimentary rocks, igneous rocks and metamorphic rocks. All these rocks, with their own properties and their weak and strong points, have made RCA a potential synthetic aggregate for pavement construction depending on the RCA percentage.

This paper presented the results of this statistical study and the associated experimental works conducted, as a component of a broader research project on designing an optimal asphalt mixture. Based on this research, it was concluded that RCA has lower value of flaky and misshapen particles in comparison with virgin aggregates. This implies that asphalt mixtures containing a certain amount of RCA can have better deformation resistance, compaction and, therefore, workability. In addition, the test results revealed that RCA exhibits comparatively more water absorption than conventional aggregate. Cracks and adhering mortar and cement paste can be significant reasons for the high water absorption of RCA. The high water absorption of RCA may result in high bitumen absorption in asphalt mixtures, and hence plays an important role in asphalt mixture design. Therefore, the selection of optimal combination of RCA and other aggregates is required to satisfy the relevant standards requirements while taking advantage of other strong points of RCA.

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