

STUDY OF THE CHARACTERISTICS OF DIFFERENT COMPONENTS OF RECYCLED CONSTRUCTION AGGREGATE (RCA): STATISTICAL STUDY IN SYDNEY

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ABSTRACT: The rapid economic growth of countries has led to the construction of new structures and infrastructures. Construction projects use up large quantities of natural resources and produce tones 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, utilization of recycled materials in construction projects can be the most promising solution to this problem. The utilization of recycled materials including recycled construction aggregates (RCA) in the pavement industry and asphalt production is particularly very promising as 90% of asphalt is made of aggregates. However, the variability in behavior and performance of RCA used in construction projects indicates the variability in their composition. Therefore, 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 composition of the RCA. This paper presents the results of the statistical study and experimental work to evaluate the characteristics of RCA as an alternative for virgin aggregate in the asphalt mixture. To this point, a series of characterization tests were conducted RCA samples collected at different dates.

Keywords: Asphalt, Igneous, Sedimentary, Metamorphic, Recycled Construction Aggregate.

1. INTRODUCTION

The demand for public infrastructure is commensurate with growth. The worldwide demand for asphalt is estimated to expand by 2.8% per year to 122.5 million metric tonnes, by 2019 [1]. This amount will continue to increase due to population growth, urbanization, and economic growth. The construction of asphalt pavements requires a large amount of aggregates. Considering resource conservation and environment protection, 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 a 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, as aggregate plays an important role in the final performance of the asphalt mixture, an understanding of their properties is essential in designing an asphalt mixture. 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 briefing provides the results of a statistical study on RCA over a one year period. The paper also covers some RCA characteristics and the specifications of RCA required for producing sustainable asphalt with high standard.

2. ROAD NETWORK AND AGGREGATE DEMAND

The road network is a vital infrastructure element in all countries, which is increasingly extending in order to meet the societies needs for the transportation of people and goods. Australia has a vast road network compared to other countries of the world. The Australian road network consists of 913,000 kilometers of roads, of which 70% is the rural network and 30% belong to the urban network. Almost 353,331 kilometers of Australian roadways are paved and the remaining 559,669 kilometers of roads are unpaved [2]. In addition to the extensive network of roads in Australia, the relatively small population of Australia has resulted in higher road length per capita in Australia in comparison with the other developed nations. Referring to the available

reports and references [3, 4], the road length per capita is about 280 m in the USA, 130 m in Great Britain, and 90 m in Japan, while the corresponding length is about 450 m in Australia. As in almost all countries, as well as Australia, the governments are taking rapid initiatives to transform the unpaved roads into paved roads. On the other hand, with the rapid growth in the economy and continuously increased consumption, a large amount of waste materials is generated in all countries. The total annual solid waste produced in Australia is estimated at about 60,870,900 tonnes from 2008 to 2009 [5]. The available studies and surveys indicate that the solid waste composition in Australia constitutes main categories including masonry materials, metals, organics, paper and cardboard, plastics, glass, hazardous wastes, and fly ash.

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 [6].
- Good Skid Resistance which depends on the microstructure and macrostructure of a pavement surface [7].

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 the sustainable development concept.

Asphalt plays a vital role in global transportation infrastructure and drives economic growth and social well-being in developed as well as developing countries [8]. Asphalt contains approximately 95% aggregate and 5% bitumen. A layer of 15 cm thick and 10 m wide for one kilometer of road requires almost 3,750 tonnes of a mixture containing aggregate and bitumen [9]. In 2007, the latest year for which figures are available, about 1.6 trillion metric tonnes of asphalt were produced worldwide [10]. 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. The demand for aggregate will continue to increase with population growth. According to the Australian Bureau of Statistics, Australia's population is expected to grow by 4 million people to 27.2 million by 2026, and reach 36 million in 2056. The provision of infrastructure to meet this growth will require an increase in the supply of aggregates and other construction materials. Referring to Australian Quarry Industry, the extractive industry currently produces about 130 million tonnes of aggregates per year and if the current demand trend continues with population growth, by 2056 the Australian industry will need to produce some 210 million tonnes of aggregates per year [3].

The cost analysis of infrastructure construction in Victoria, the single biggest cost component in an infrastructure construction is materials [11]. This report also forecasts that the infrastructure construction costs will most likely increase on average by 3.6% per year over the next 10 years in Victoria, with materials cost as the biggest contributor to these future cost increases. The Victorian example is an indicator 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 an 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, 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 [12]. Therefore, it is essential to recognize the importance of locally supplied construction materials to the provision of affordable public infrastructure to ensure affordable supply. To this point, the identification of new and innovative resources of construction materials (like recycled aggregates) is of high importance in this regard.

3. A REVIEW ON RECYCLED CONSTRUCTION AGGREGATES (RCA) IN AUSTRALIA

The Australian Quarrying Industry Estimates average consumption of aggregates across Australia

at around 7 tonnes per person per annum. One area of continuing innovation is in the use of recycled materials. The construction and demolition sector is Australia's biggest generator of waste which 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 [13]. 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 [3]. 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. Fig.1 illustrates the sources of RCA in Australia, noting that Man Sand stands for "manufactured sand".

Choosing RCA can be considered as a smart option because it is about extracting value from existing resources that would otherwise be wasted while reducing the need to dig up more virgin rocks. Even if it be assumed that there is no physical shortage of rocks in Australia, a range of social and environmental issues can be associated with the quarrying of virgin materials. 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 lifecycle, largely due to avoiding the energy needed to quarry rock.



Fig.1: Sources of RCA in Australia [14]

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.

3.1 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 into 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 behavior.
- Metamorphic rocks show a great variety in structure and composition and properties. The metamorphism has often resulted in hard minerals and high intact rock strength. 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 the 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) have 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 groups 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. Moreover, the skid resistance will be impacted by the aggregate composition. Asphalt concrete with a crushed brick will provide differential wearing of the asphalt by creating a fresh and rugose surface and subsequently will enhance skid resistance [15]. 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 the 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.

3.2 Statistical study on RCA in Sydney

The variability in the behavior 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 center in Sydney. For this purpose, the RCA is collected at different dates over one year and is categorized into different geological groups of sedimentary, igneous, and metamorphic, as illustrated in Fig. 2 (from left to right).



Fig. 2 Studied Rocks from RCA Sample (a) Sedimentary, (b) Igneous, (c) Metamorphic

The results of sorting RCA samples into different geological groups are presented in Fig.3. It is intended to create a database containing the composition and characteristics of RCA produced in Sydney in twelve months.

As the results of the 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.

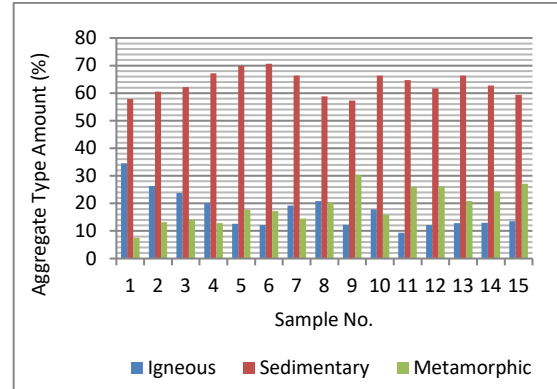


Fig.3 Summary of Test Results for the Classification of Recycled Construction Aggregate (RCA)

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. In an investigation, it has been shown that the addition of small quantities of crushed brick to asphalt mixture, improves the skid resistance of this material [16]. Therefore, the variability in RCA composition can result in making a superior hot mix asphalt (HMA) to Natural aggregate mixtures.

3.3 Study on RCA Characteristics

As discussed previously, the surface (wearing) course requires two major characteristics of Good Resistance to shear forces and adequate skid resistance.

Aggregates with good particle shape will increase the wearing course resistance to shear forces [16]. 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 [17].

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 two tests on RCA and basalt are given in Table 1.

Table 1 the Results of Particle Shape and Flakiness Index Test for RCA and Basalt and Australian Standard Limits for Dense Graded Asphalt

Test	RCA (%)	Basalt (%)	Australian Standard Limit
Particle Shape	6.2	18.3	35% (max)
Flakiness Index	6.9	19	25% (max)

As presented in Table 1, for these two parameters which are two important characteristics affecting asphalt mixture strength and stability; RCA displays the smaller value in comparison with basalt. This can be one of the strong points of RCA as flakiness index and particle shape are the two important properties that affect the inter-particle interlock in asphalt mixtures and subsequently influence the shear resistance of asphalt mixtures.

Table 2 the Results of Water Absorption and Particle Density Test for Various Aggregates

Property	Water Absorption (%)	Particle Density (gr/cm ³)	Australian Standard Limit
RCA	6.30	2.370	
Sedimentary Rocks in RCA	7.64	2.264	2% (max) Water Absorption Limit
Igneous Rocks in RCA	2.03	2.575	
Metamorphic Rocks in RCA	5.86	2.488	
Basalt	1.64	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. 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 are considered as part of this research in order to obtain detailed information and data on this key property of RCA. The results of water absorption and particle density test in accordance with AS 1141.6.1 (2000) are presented in Table 2.

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 the high proportion of sedimentary rocks in RCA. In addition, the water absorption of igneous rocks in RCA is higher than the corresponding value of virgin igneous rocks which can be as a result of some cement paste and other impurities adhering to recycled igneous rocks.

3.4 Results and Discussions

As presented in the previous sections, in this research, the characteristics of RCA and different aggregate types in RCA were investigated through performing statistical studies and conducting a series of tests. The results of RCA classification reveals that RCA is composed of mostly sedimentary rocks, igneous rocks, and metamorphic rocks. Each of these aggregate types has their own properties with weak and strong points for asphalt production which makes RCA appropriate for use as an aggregate in asphalt mixture depending on the RCA percentage. For instance, as adequate skid resistance is one of the requirements in surface (wearing) course, the existence of igneous and metamorphic groups can be one of the strong points of RCA as these two groups are generally hard and resistant to polishing. In many research studies [16], it is shown as feasible to use crushed brick materials as skid resistance aggregates. Moreover, for some parameters such as Flakiness Index and Particle Shape which are two dominant characteristics having a significant impact on asphalt mixture shear resistance, strength, and stability; RCA displays a smaller value in comparison with basalt. This also can be another strong point of RCA as flakiness index and particle shape are the two important properties for proper compaction, deformation resistance, and workability of asphalt mixture [18, 19].

Since this research aims to investigate the characteristics of RCA for the partial replacement of coarse virgin aggregate in asphalt mixtures, the water absorption tests were conducted on RCA, different aggregate types (igneous, metamorphic, sedimentary) in RCA, and virgin igneous aggregate.

The results of these tests are presented in Fig. 4 in order to have a better comparison between the aggregates properties.

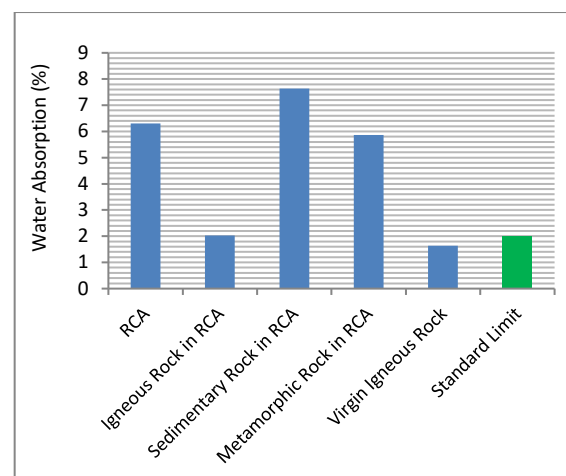


Fig. 4 The Result of Water Absorption Test on Different Aggregates

Fig. 4 clearly reveals that the water absorption of RCA is higher than the corresponding value of

virgin materials and the Australian Standards limit, because it is well known that water absorption requires linked and open cracks in the structure of aggregate and RCA contains cracks due to the existence of metamorphic and sedimentary rocks with high water absorption, as illustrated in Figure 13. Among these two types of aggregates, sedimentary rocks play a more important role in RCA absorption as a result of a high proportion of sedimentary rocks in RCA. The high amount of sedimentary rocks in RCA samples collected from a supplier in Sydney has resulted in RCA with water absorption within the range of 5.5% and 6.7%, respectively.

4. CONCLUSION

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 database 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 characterization tests have been conducted on different aggregate types of RCA samples collected at different dates over a twelve month period. The results of the statistical study on RCA samples over time indicate that:

- RCA is composed of mostly sedimentary rocks (64%), igneous rocks (17%) and metamorphic rocks (19%).
- 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.

In addition, this paper presented the results of the experimental works conducted on collected RCA sample over one year, as a component of a broader research project on designing an optimal asphalt mixture. Based on this research, it was concluded that:

- RCA has a 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.
- RCA exhibits comparatively more water absorption than the conventional aggregate. Cracks and adhering mortar and cement paste can be significant reasons for the high water absorption of RCA which can be clearly observed in the results of image analyses. 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 an 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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