

Utilization of a By-Product from Alumina Industry as Roadway Materials

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Abstract (10 points)

Australia produces approximately 40% of the world's bauxite and over 30% of the world's alumina. Each year, about 25 million tonnes of sand residues are produced in Australia. The management and containment of large impoundment areas are costly. The sustainable use of coarse sand residues for road construction is an attractive option with a high potential for large volume reuse. During the extraction of alumina from bauxite ore using the Bayer process, a fine residue is produced called red mud. In Western Australia, Darling Range bauxite deposits contain high levels of quartz, which results in a coarse residue fraction also being produced. This study focuses on whether a coarse sand residue is a viable option for use as a road base material in Western Australia. The soil stabilisation technique, a pozzolanic- stabilised mixture, was used to improve the properties of a coarse sand residue to satisfy minimum requirements of road bases. The intent of this stabilisation technique is to use potential by-products from industry in Western Australia as stabilising materials. A pozzolanic - stabilised mixture consisting of Class F fly ash, a by-product from a coal power station, and activators, the by-product from the quicklime manufacturing in terms of lime kiln dust, were employed to develop pozzolanic activity. Once the appropriate mixture of a coarse sand residue, fly ash, and activators was established (based on a maximum dry density and a value of unconfined compressive strength), a set of laboratory tests were performed. These included an unconfined compressive strength test, a resilient modulus test, and a permanent deformation test. Comparisons were made between the stabilised residue and the conventional road base material in West Australia (crushed rock with the addition of 2% General Purpose (GP) Portland Cement.). The results of this study show that the performance of the stabilised residue is superior to that of the standard use material. Our findings indicate that stabilised residue can provide improved performance when used as road base material in Western Australia.

1. Introduction

In Western Australia, numerous bauxite deposits have underpinned the long-term development of the alumina industry. Western Australia has four alumina refineries. Three are owned by Alcoa World Alumina (Alcoa) and are located at Kwinana, Pinjarra and Wagerup. Worsley JV has one refinery at Worsley near Collie. In 2004, the total combined Alumina production of the four refineries was approximately 11 million tonnes. The Australian aluminium industry is aware that its long term viability is dependent on responsible resource management. This study focuses on whether a coarse sand residue is a viable option for sustainable use as a road base material in Western Australia.

2. Materials

A coarse sand residue used in this study was sourced from alumina refineries in Western Australia. A coarse sand residue samples were collected randomly from an impoundment area and kept in sealed plastic containers. A coarse sand residue was characterised in terms of basic geotechnical properties to evaluate, initially, the possibility of using a coarse sand residue for

engineering works. The basic geotechnical properties of a coarse sand residue, including its specific gravity, particle size distribution, Atterberg limits, compaction characteristics, CBR values, water conductivity, and shear strength were investigated. The results of the investigation are shown in Table 1 and Fig. 1.

The particle size distribution for a coarse sand residue is shown in Fig. 1. The majority of the fractions lie within the defined sand particle size distribution (PSD), with a small fraction being defined as silt. Moreover, a coarse sand residue can be grouped in the soil group SP-SM poorly graded sands mixture with silty soils, based on the unified soil classification system (USCS).

The particles shown in Fig. 2 illustrate the different features of particle appearance of a coarse sand residue and natural sand. The natural sand is well rounded and frosted, whereas the particles of a coarse sand residue formed by crushing large mineral chunks have sharp edges and corners. The surfaces are not striated, frosted, or etched.

The available data indicates that a coarse sand residue has a high potential for use as a construction material and for geotechnical engineering.

Table 1 Geotechnical properties of a coarse sand residue

	Values			
	3.03			
	None Plasticity			
Compaction	Modified		Standard	
	MDD(t/m^3)	OMC(%)	MDD(t/m^3)	OMC(%)
	1.83	17.6	1.60	20.2
CBR	Modified		Standard	
	Soaked(%)	Unsoaked(%)	N/T***	
	55	48		
Water Conductivity	Coefficient of Permeability (cm/sec)			
	Void Ratio, $e = 0.65^*$		Void Ratio, $e = 0.89^*$	
	1.54×10^{-4}		6.93×10^{-4}	
Shear Strength**	Friction Angles, ϕ (°)			
	Void Ratio, $e = 0.65^*$		Void Ratio, $e = 0.89^*$	
	At Ultimate Strength	At Peak Strength	At Ultimate Strength	At Peak Strength
	40.03	45.00	37.48	40.56

*The compacted a coarse sand residue at the condition of the standard compaction test has a void ratio of 0.89 and at the condition of the modified compaction test, it has a void ratio of 0.65.** Shear strength properties were conducted by the standard direct shear test. *** N/T = Not tested

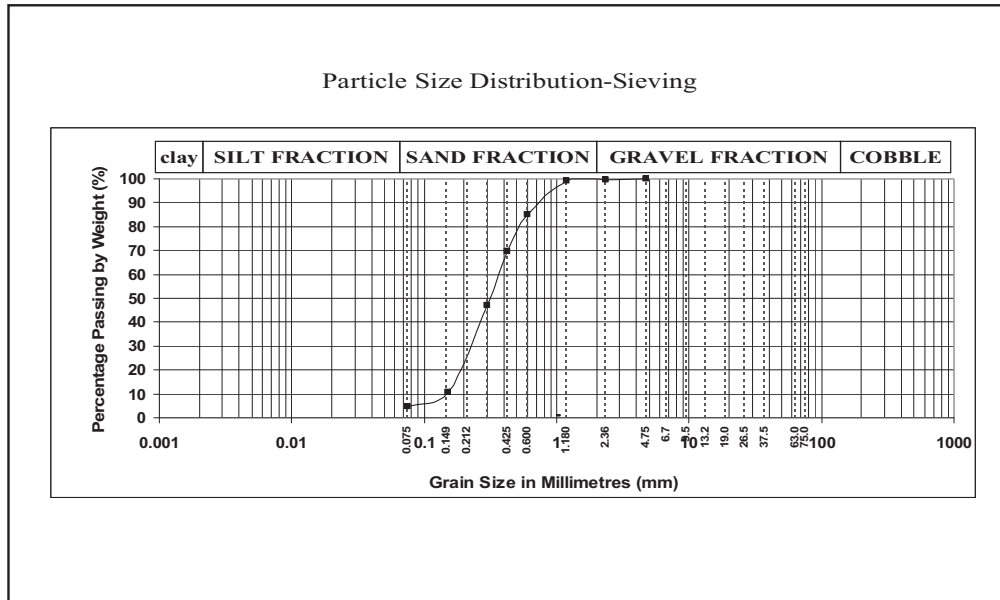


Fig.1 Particle size distribution of a coarse sand residue

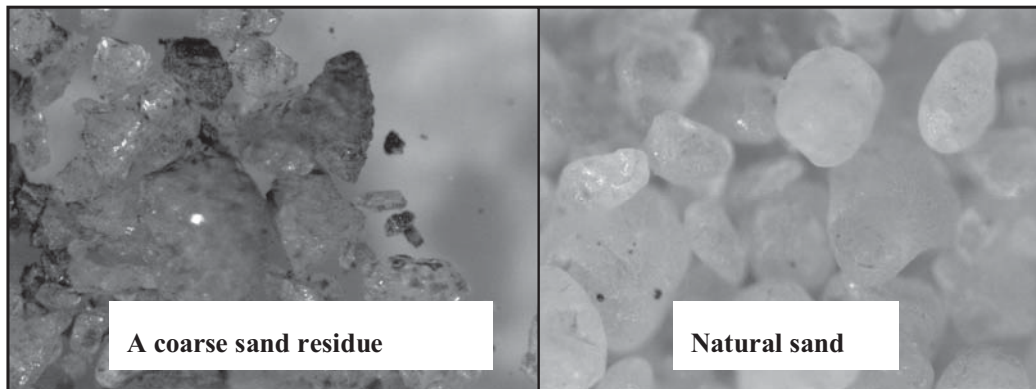


Fig. 2 Optical microscopy comparison of a sand residue and natural sand

Based on the geotechnical properties alone, a coarse sand residue would appear to be a good fill material. The angularity of coarse sand residue particles provides the high shear resistance necessary from a geotechnical engineering perspective. However, the use of a coarse sand residue for road construction required further investigated in particular from a pavement engineering perspective. Road construction materials have to resist the traffic load which is quite different to the static loads from buildings. It is proposed that a coarse sand residue has the potential to be used in road construction if the fundamental properties can be improved.

3. Research Methodology

The research methodology in this study was divided into two parts.

The first part was the stabilisation of a coarse sand residue. By employing a soil stabilisation technique using pozzolanic stabilised mixtures (PSM), a coarse sand residue was stabilised to meet the requirements for road construction. In this case, the PSM consisted of a

coarse sand residue combined with Class F fly ash (a by-product from a coal power station), an activator (lime kiln dust) and water. The use of fly ash, lime kiln dust and water created a pozzolanic reaction which improved coarse sand residue properties. The proportion of a coarse sand residue, fly ash and lime kiln dust was determined by compaction and unconfined compressive strength testing of different mixtures. The objective was to establish the mixture that achieved an unconfined compressive strength between 0.6MPa and 1.0 MPa, which is the range of road base material specifications in Western Australia. Alternative activators could be considered if the lime kiln dust does not provide sufficient strength (details of the stabilisation process of a coarse sand residue are shown in Fig. 3).

The second part of this study was the verification of the chosen mix. The commonly used base coarse material which satisfies Western Australia Main Roads' specifications is crushed rock with 2% GP cement. This was used as the reference or control material. Samples were tested in a Repeat Load Triaxial Apparatus to determine the resilient modulus and permanent deformation characteristics. The method was in accordance with the standard method of Ausroads APRG 00/33-2000 [1].

4. Results and discussion

4.1 The stabilisation of a coarse sand residue

The first stage of a coarse sand residue stabilisation was the determination of the optimum proportion of fly ash.

Fig. 4 shows the compacted dry density versus the water content curves for various mixtures. The results show that a coarse sand residue and fly ash mixes achieve higher maximum dry density than the corresponding components. Best dry densities were achieved with fly ash contents in the range between 20 and 40 %. Increasing the fly ash content further to 50% caused a relative reduction in the maximum dry density. Studies of silty sands similar to these mixtures reveal that for a low content of non-plastic silt (0 to 25%), the dry density will increase with increasing fines content because the fines occupy the void between sand particles. However, if the fines content exceeds 25%, there is a decrease in the dry density [2] For a coarse sand residue, addition of fly ash increased the dry density to a maximum at about 30% fly ash. Higher proportions of fly ash cause the coarse sand residue particles to separate and fine particle interactions begin to dominate. For fly ash contents of 40% and 50%, the coarse sand residue particles tend to be separated, floating in a fly ash matrix, hence the density decreases.

The main objective of this stage was to find a coarse sand residue and fly ash mixture having the highest dry packing density. From Fig. 4 the highest density was for 70% a coarse sand residue with 30% fly ash (dry weight). This mixture had an optimum water content of 9.2%.

The above optimum mixture was used to determine the appropriate amount of activator (lime kiln dust). Mixtures of differing levels of lime kiln dust were tested for unconfined compressive strength (UCS). Fig. 5 illustrates the results of these UCS tests.

Fig. 5 shows the effect of curing time on the unconfined compressive strength of various stabilised sand mixes. All the specimens increased with curing time.

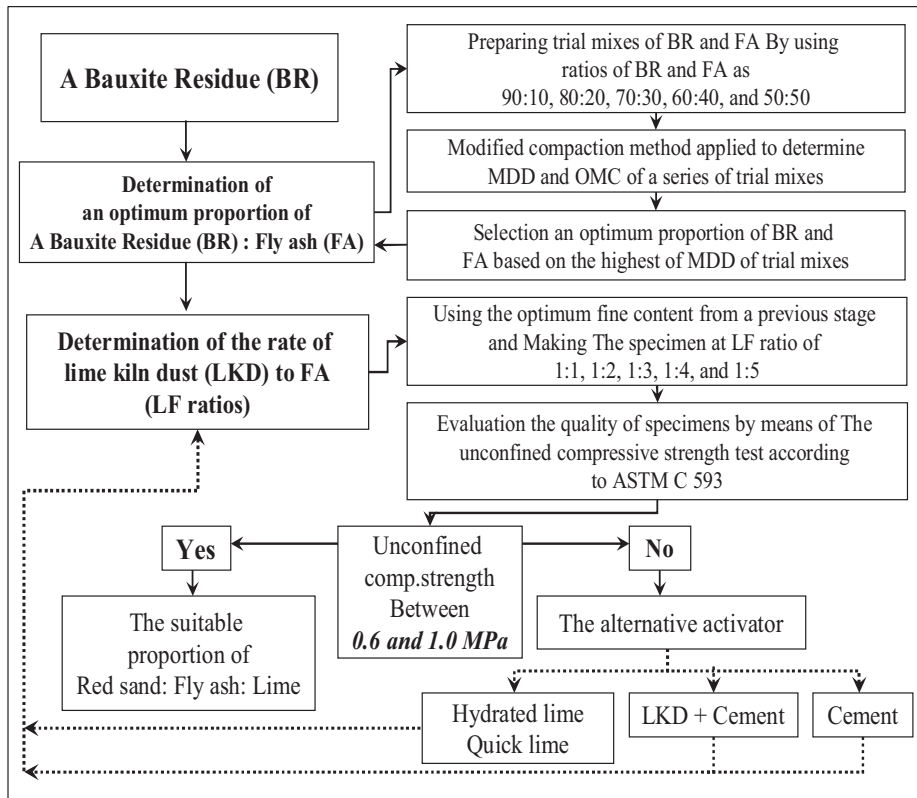


Fig. 3 A coarse sand residue stabilisation details

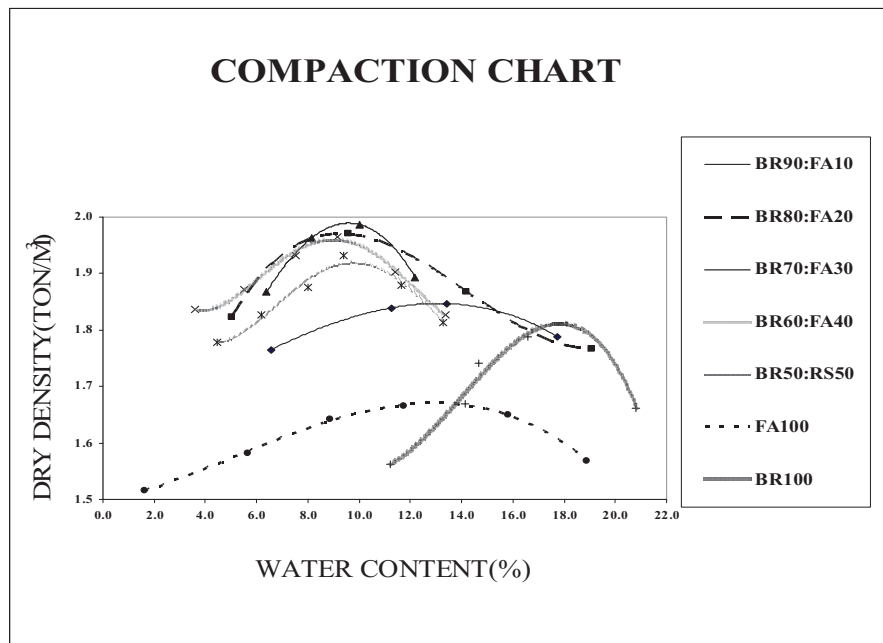


Fig. 4 Compaction curves of a coarse sand residue and fly ash mixtures.

Results clearly show that increasing the ratio of lime kiln dust from 1:5 to 1:1 diminished the unconfined compressive strength. WA Main Roads Department has a specification for UCS of between 600 kPa and 1000 kPa at a curing time 7 days. LF ratios of 1:5 and 1:4 achieved this specification, with the lower content of lime kiln dust favoured.

Based on the results of the compaction and unconfined compressive strength tests, the selected mix for further investigation was 70% of a coarse sand residue, 25% of fly ash and 5% of lime kiln dust (dry weight).

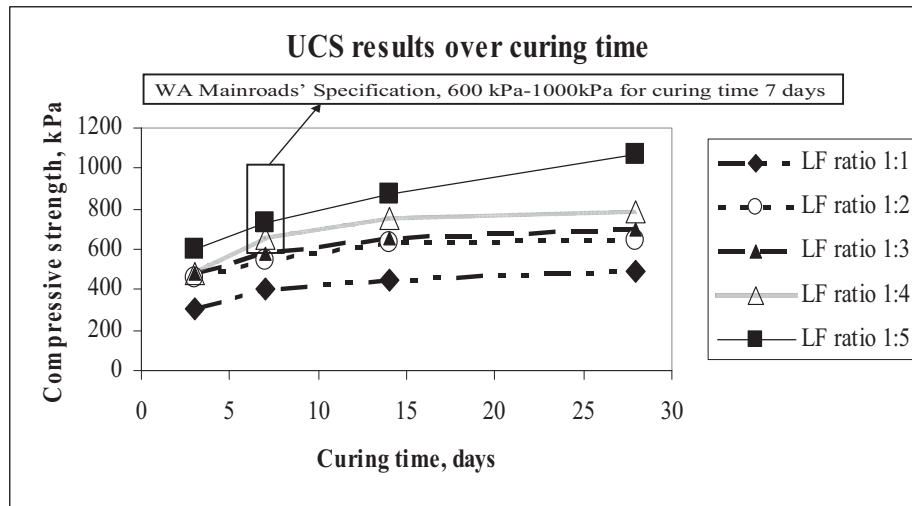
4.2 Verification of a stabilised coarse sand residue

Resilient modulus and permanent deformation were used in this verification stage because both characteristics are significant to road performance. Successful pavement layers must exhibit high resilient modulus in order to spread load adequately and to reduce resilient deformation of upper bituminous layers. The pavement must resist internal permanent deformation which might contribute to surface rutting [3]. The resilient modulus or stiffness of pavement structures is also a critical factor in determining the thickness and composition of pavement layers. It simulates the pavement behaviour under repeated loading conditions, replicating traffic loading conditions. The permanent deformation of pavement materials is manifested as rutting and shoving, the visible damage on the road coming from the excess deformation of the pavement. This is caused by the pavement material having insufficient stability to cope with the prevailing loading and environmental conditions. Consequently, both resilient modulus and permanent deformation characteristics are suitable parameters to examine the suitability of a stabilised coarse sand residue for road construction.

In Western Australia, crushed rock mixed with 2% General Purpose (GP) cement achieves the required standards and hence is used as the control or reference material. It is proposed that if the stabilised coarse sand residue is equal to or better than the control sample in terms of resilient modulus and permanent deformation characteristics, then it can be concluded that the stabilised coarse sand residue can be used for road base material in Western Australia. For these tests, the stabilised coarse sand residue mixture contained 70% a coarse sand residue, 25% fly ash and 5% lime kiln dust.

The results of resilient modulus testing can be seen in Fig. 6. Clearly the performance of the stabilised coarse sand residue exceeds the reference material. The stabilised coarse sand residue exhibits a higher resilient modulus than that of the commonly used road base material in Western Australia region for all different stress states.

Fig. 7 shows the permanent deformation characteristics of a stabilised coarse sand residue and the crushed rock added with 2% GP cement. It can be clearly seen that the permanent deformation of the stabilised coarse sand residue is smaller than the conventional material at every stress stage applied on the specimens. Hence it can be concluded that a stabilised coarse sand residue could be used for base course construction of roads.



LF ratio = the ratio of lime kiln dust to fly ash

Fig.5 Unconfined Compressive Strength of stabilised sand mixes

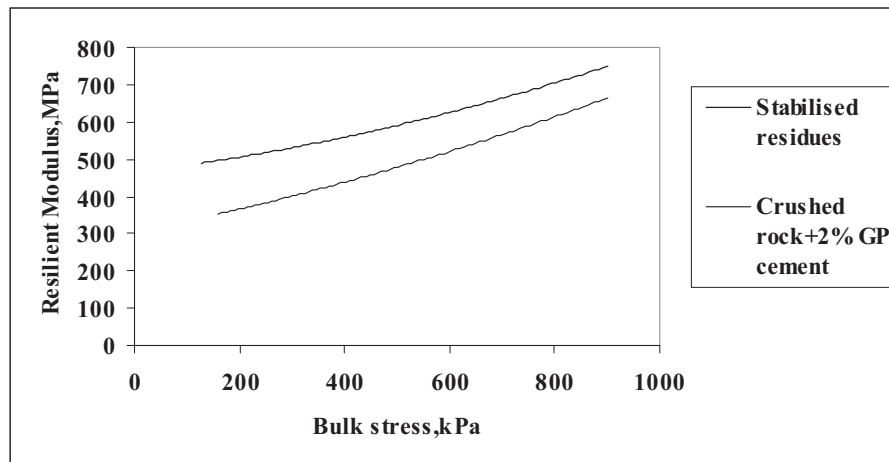


Fig. 6 Resilient modulus against different bulk stress for stabilised coarse sand residues and crushed rock with 2%GP cement

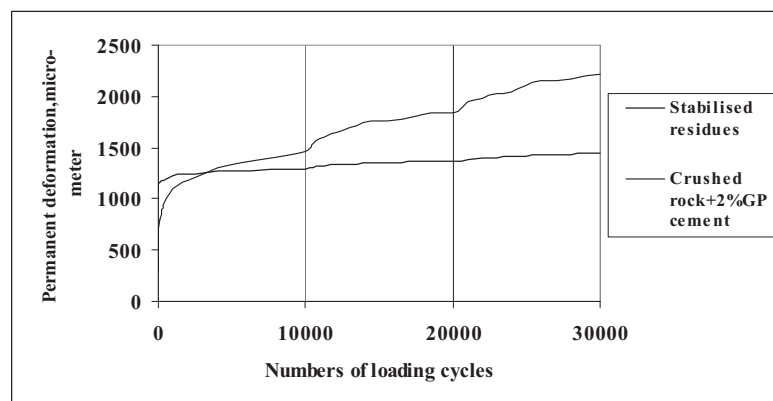


Fig.7 Permanent deformation against load cycles for stabilised coarse sand residues and crushed rock added with 2% GP cement

5. Conclusions

The stabilised coarse sand residue is a viable option for use as a base course material in road construction in Western Australia. The stabilised coarse sand residue exhibits resilient modulus and permanent deformation characteristics that exceed that of the commonly used material for road bases (crushed rock added with 2% GP cement).

6. References

- [1] Young, B.T. and R. Brimble, *Austrroads Repeated Load Triaxial Test Method-Determination of Permanent Deformation and Resilient Modulus Characteristics of Unbound Granular Materials Under Drained Conditions*, in *APRG DOCUMENT APRG 00/33(MA)*, A.P.R. Group, Editor. 2000, Austrroads.
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