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Title: **"Sustainable Use of a Bauxite Residue (red sand) in terms of Roadway Materials"**

Sustainable use of a Bauxite Residue (red sand) in terms of Roadway Materials

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ABSTRACT: Australia produces approximately 40% of the world's bauxite and over 30% of the world's alumina. Each year, about 25 million tonnes of bauxite residues are produced in Australia. The management and containment of large impoundment areas are costly. The sustainable use of coarse bauxite 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 fraction has been termed red sand with a typical particle size in excess of 90 micron. Typically, red mud and red sand are produced in almost equal quantity. Processing of red sand can neutralise the residual caustic and lower the salt content as required. This study focuses on whether red sand 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 red sand 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 red sand, 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 red sand 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 red sand is superior to that of the standard use material. Our findings indicate that stabilised red sand can provide improved performance when used as road base material in Western Australia.

Keywords: SUSTAINABLE, BAUXITE RESIDUES, RED SAND, LIME KILN DUST, ROAD CONSTRUCTION

1 Introduction

In Western Australia, numerous bauxite deposits, located in the Darling Range south of Perth, 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. Alcoa has established a research program on the utilisation of bauxite residues, co-operating with The Centre for Sustainable Resource Processing (CSRP), various universities, and research institutes throughout Australia. This study focuses on whether red sand is a viable option for sustainable use as a road base material in Western Australia.

2 Red Sand

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 fraction has been termed red sand, with a typical particle size in excess of 90 micron. Typically, red mud and red sand are produced in almost equal quantity. Approximately 20,000 tonnes of mud and a similar tonnage of sand are produced daily across Alcoa's three Western Australian refineries (Cooling and Jamieson, 2004). Processing of red sand can neutralise the residual caustic and lower the salt content as required.

The red sand used in this study was sourced from Alcoa's Kwinana refinery. Red sand samples were collected randomly from an impoundment area and kept in sealed plastic containers. Samples were atmospherically carbonated prior to testing at the Department of Civil Engineering, Curtin University of Technology.

The red sand was characterised in terms of basic geotechnical properties to evaluate, initially, the possibility of using red sand for engineering works. The basic geotechnical properties of red sand, 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 Figure 1.

The particle size distribution for red sand is shown in Figure 1. The majority of the fractions lie within the defined sand PSD, with a small fraction (ca 5%) being defined as silt. Moreover, red sand 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 Figure 2 illustrate the different features of particle appearance of red sand and natural sand. The natural sand is well rounded and frosted, whereas the particles of red sand formed by crushing large mineral chunks have sharp edges and corners. The surfaces are not striated, frosted, or etched.

Table 1. Geotechnical properties of red sand.

Properties	Values			
Specific gravity	3.03			
Atterberg limit	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, ø (˚)			
	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 red sand 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

Figure 1. Particle size distribution of red sand.

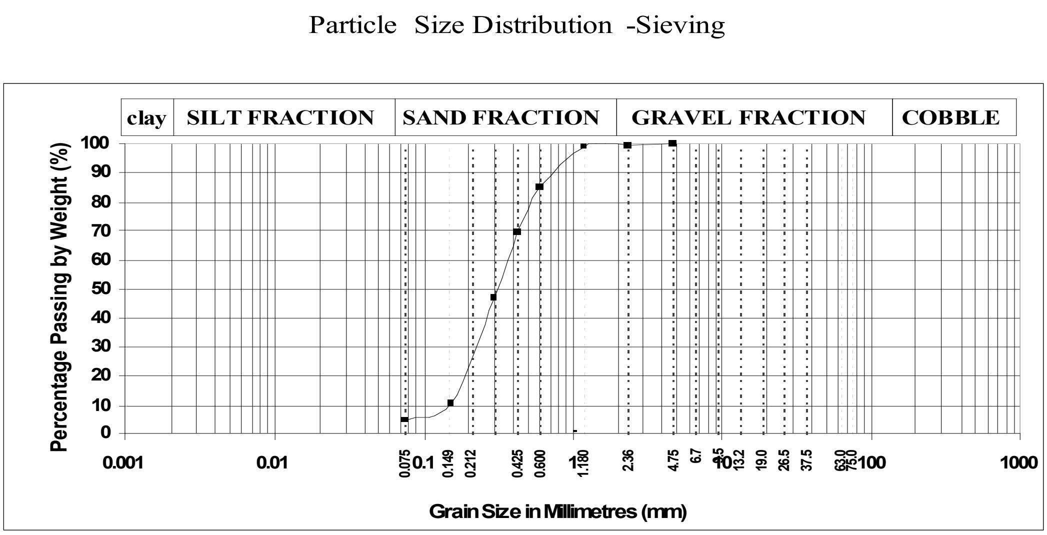


Figure 2. Optical microscopy comparison of red and natural sand

Typical chemical composition of red sand is shown in Table 2.

Table 2. The typical chemical composition of red sand (Jamieson E, 2005)

Compounds	Percentages (%)
Al_2O_3	10
Fe_2O_3	26
SiO_2	56
CaO	0.6
Na_2O	0.4

The available data indicates that red sand has a high potential for use as a construction material and for geotechnical engineering. Based on the geotechnical properties alone, red sand would appear to be a good fill material. The angularity of red sand particles provides the high shear resistance necessary from a geotechnical engineering perspective. However, the use of red sand 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 red sand has the potential to be used in road construction if the fundamental properties can be improved.

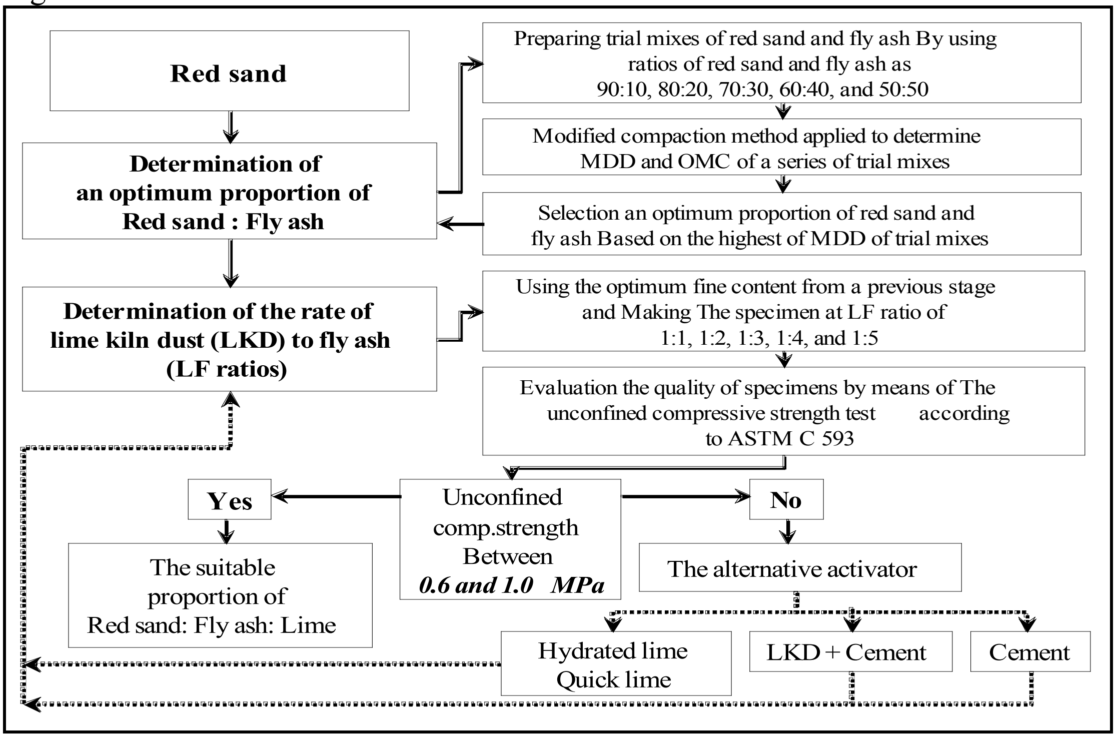
3 Research Methodology

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

The first part was the stabilisation of the red sand. By employing a soil stabilisation technique using pozzolanic stabilised mixtures (PSM), red sand was stabilised to meet the requirements for road construction. In this case, the PSM consisted of red sand 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 red sand properties. The proportion of red sand, 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 red sand are shown in Figure 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 (Voung, 2000).

Figure 3. Red sand stabilisation details



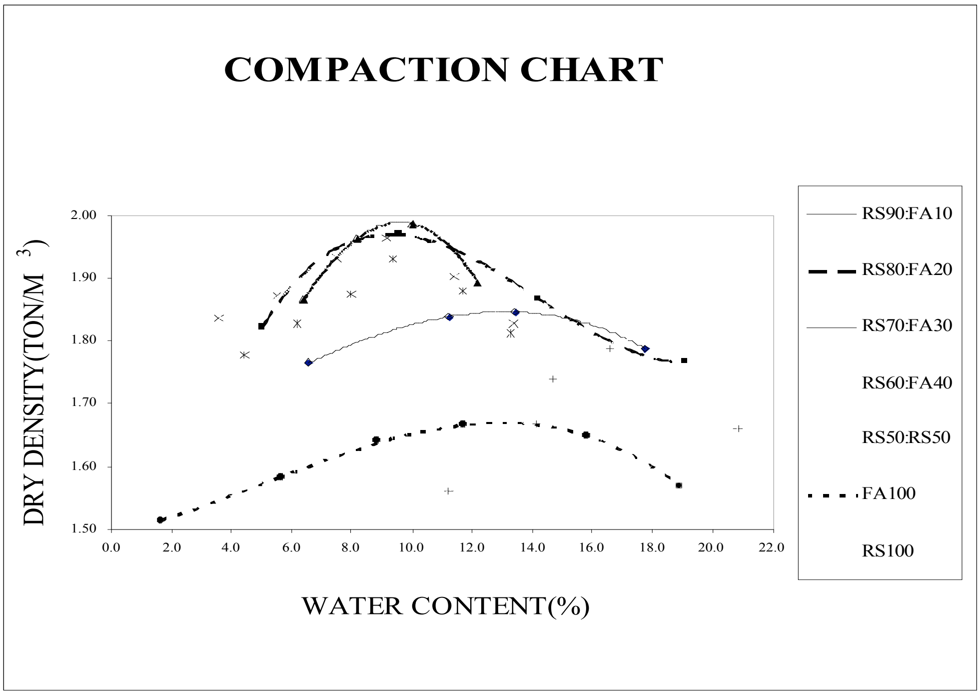
4 Results and Discussion

4.1 *The stabilisation of red sand*

The first stage of red sand stabilisation was the determination of the optimum proportion of fly ash.

Figure 4 shows the compacted dry density versus the water content curves for various mixtures. The results show that red sand 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 (Kuerbis et al., 1988). For red sand, addition of fly ash increased the dry density to a maximum at about 30% fly ash. Higher proportions of fly ash cause the red sand particles to separate and fine particle interactions begin to dominate. For fly ash contents of 40% and 50%, the red sand particles tend to be separated, floating in a fly ash matrix, hence the density decreases.

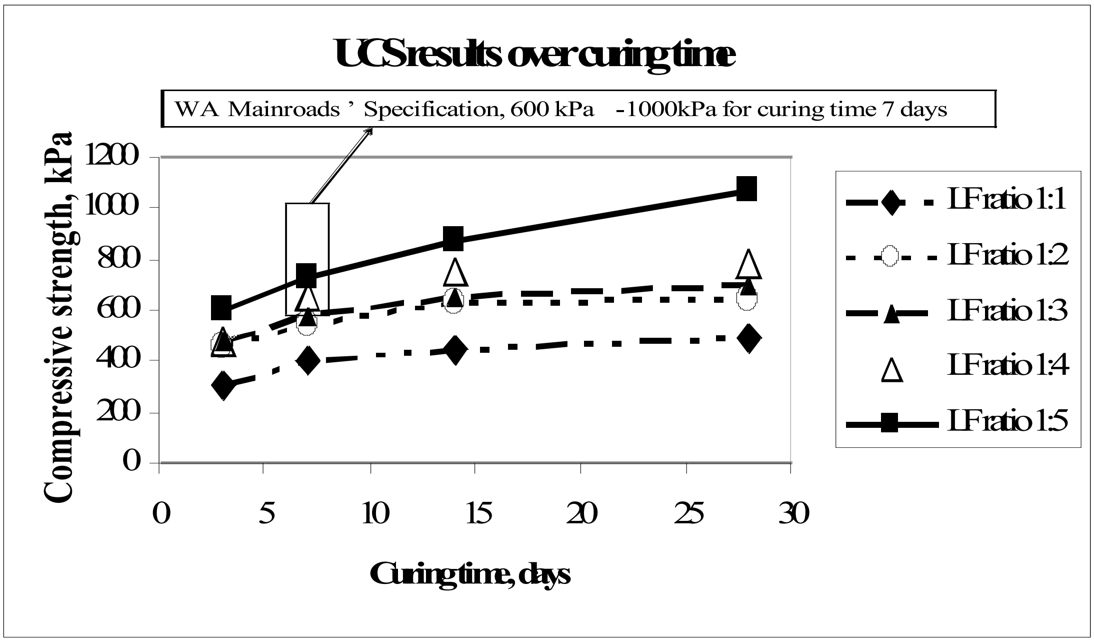
Figure 4. Compaction curves of red sand and fly ash mixtures.



The main objective of this stage was to find the red sand and fly ash mixture having the highest dry packing density. From Figure 4 the highest density was for 70% red sand 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). Figure 5 illustrates the results of these UCS tests.

Figure 5. Unconfined Compressive Strength of stabilised sand mixes.



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

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

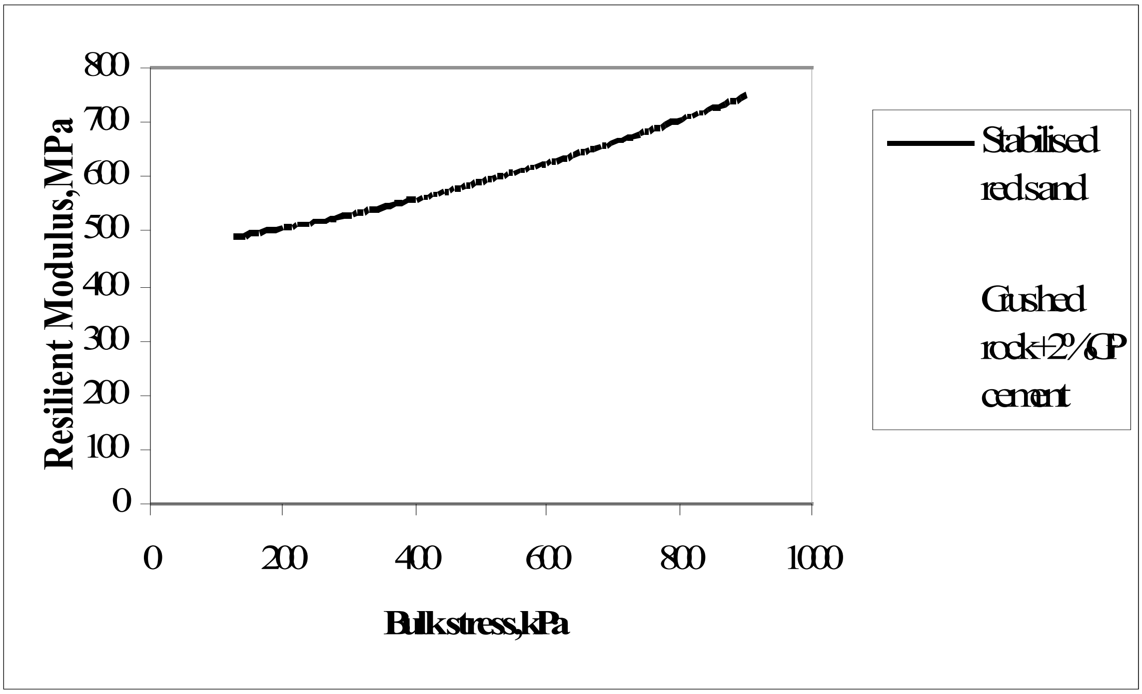
Based on the results of the compaction and unconfined compressive strength tests, the selected mix for further investigation was 70% of red sand, 25% of fly ash and 5% of lime kiln dust (dry weight).

4.2 *Verification of stabilised red sand*

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 (Dawson A.R. , 1993). 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 stabilised red sand 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 red sand 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 red sand can be used for road base material in Western Australia. For these tests, the stabilised red sand mixture contained 70% red sand, 25% fly ash and 5% lime kiln dust.

Figure 6. Resilient modulus against different bulk stress for stabilised red sand and crushed rock with 2%GP OPC.



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

Figure 7. Permanent deformation against load cycles for stabilised red sand and crushed rock added with 2% GP cement.

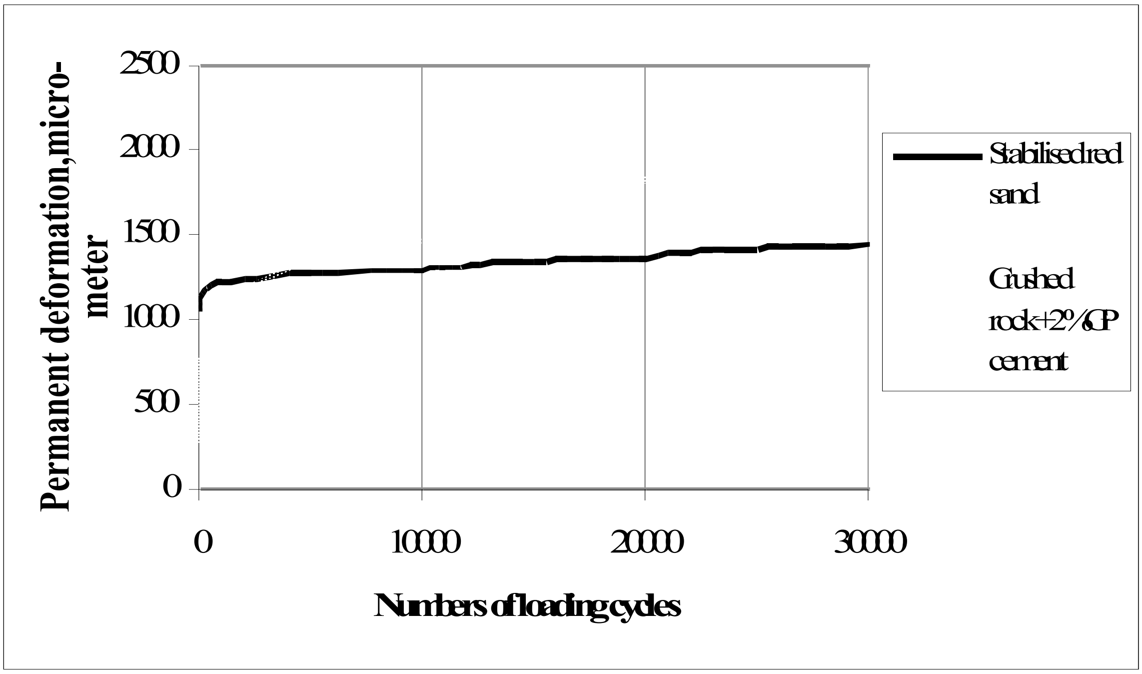


Figure 7 shows the permanent deformation characteristics of the stabilised red sand and the crushed rock added with 2% GP cement. It can be clearly seen that the permanent deformation of the stabilised red sand is smaller than the conventional material at every stress stage applied on the specimens.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

5 Conclusions

Stabilised red sand is a viable option for use as a base course material in road construction in Western Australia. The stabilised red sand 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).

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