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Use of fibre reinforced crushed building demolition waste in road construction

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ABSTRACT: The recycled aggregate from crushed building demolition waste (RCBDW) contained significant foreign particles such as brick and wooden pieces and failed to meet the requirements for acceptance as base and sub base materials for pavements. The potential of using fibre and fibre plus small percentage of cement stabilised RCBDW aggregate for constructing road base and/or sub base was investigated experimentally and the results reported in this paper. In addition to the traditional properties such as CBR and UCS, the resilient modulus and the accumulation of permanent strain of recycled aggregate were investigated from cyclic triaxial testing for different percentages of fibre using two different curing methods. The test results indicate that the CBR and resilient modulus of the RCBDW aggregate could not be improved by the addition of the particular type of fibre alone. However, its resilient modulus could be improved slightly (by about 10%) and the strain due to permanent deformation decreased by over 100% by reinforcing it with 0.25% fibre plus 3% cement compared to 3% cement alone. This study further indicates that the addition of fibre alone also would reduce the permanent deformation and therefore enhances the pavement's ability to resist rutting.

1 INTRODUCTION

With increasing need for repair and renewal of buildings, the production of building demolition waste continues to grow. At present the primary method of disposing this waste is in landfills. Depleting the space available for landfills has seen marked increase in disposal costs. A solution to the problem is to utilize this crushed building demolition waste material, hereafter referred as RCBDW aggregate, in road (pavement) construction. A research program was initiated to investigate the potential of using this RCBDW aggregate for constructing the sub base and base of pavements (see Fig. 1).

The quality assurance of aggregates for pavement construction is usually specified in terms of limitations in the particle size distribution, soundness of the aggregates, foreign particle content, moisture-density relationship and California Bearing Ratio (CBR). Since RCBDW aggregate was quite variable and consisted of significant foreign particles such as brick and wooden pieces, it failed to meet some of these requirements for acceptance as base and in some instances as even sub base materials for pavements. Consequently, there is considerable reluctance in using RCBDW aggregate for road construction. The potential of using this RCBDW aggregate in road construction by mixing it with small percentages of fibre and cement plus fibre was investigated experimentally and the results are discussed in this paper.

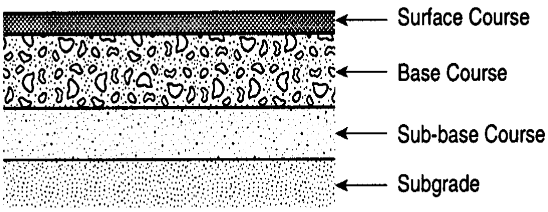

Fig. 1 Schematic of a typical pavement cross section

In the mechanistic method of pavement design, the different materials are often characterised by an elastic modulus commonly called the resilient modulus. The resilient moduli of the base and sub-base materials spread the wheel loads so that the weaker subgrade is subject to a smaller stress pulse. The term "resilient modulus" was first introduced during the 1950s following the pioneering work of Hveem and Seed (1955), which recognise that elastic modulus is a simple idealisation of real behaviour under cyclic loading. Permanent strain will accumulate with load repetitions. Accumulation of permanent strain is associated with certain modes of pavement failures due to load repetition. A number of design criteria reported in the literature are based on the assumption that the accumulation of permanent strain can be correlated with resilient strain. Hence the resilient moduli of the road foundation materials has been given a pivotal role in mechanistic method of pavement design (Lekarp et al 2000).

Therefore, in addition to the traditional properties such as CBR and unconfined compressive strength, the resilient modulus and the accumulation of permanent strain of recycled aggregate were investigated from cyclic triaxial testing for different percentages of fibre and cement as well as two different curing methods. The results of this investigation are discussed in relation to mechanistic method of pavement design in this paper.

2 FIBRE REINFORCEMENT

A review of the literature reveals that several laboratory investigations have been carried out on fibre-reinforced materials but all these were limited in their scope to soil reinforcement for backfill and/or sandy soils (Gray, 1983; Alwahab, 1995; Guido, 1995; Gregory et al., 1998; Stauffer and Holtz, 1995; Liausu and Juran, 1995; Morel and Gourc, 1997; Nataraj and McManis, 1997; Webster and Santoni, 1997; and Santoni et al., 2001 among others). Moreover, these studies report the results from laboratory tests such as unconfined compressive strength, consolidated drained and CBR but the assessment of resilient characteristics under repeated loading conditions were not generally considered. The research reported in this paper studied the effect of fibre and fibre plus cement on RCBRW aggregate and the investigation focussed on the assessment of resilient characteristics from cyclic triaxial testing. The results obtained so far from this ongoing research are reported.

Santoni et al., 2001 studied the effects of using different types of fibre to reinforce sandy soil and suggest that fibrillated fibres are superior to other types such as tape, monofilament and mesh. Therefore, a fibrillated polypropylene type fibre (Fibermesh® - manufactured by Synthetic Industries Ltd., USA) easily available in Australia was used in this study (see Table 1 for its properties).

Table 1. Summary of fibre Properties from manufacturer's literature.

Material	Polypropylene
Specific Gravity	0.9
Fibre Length	12 mm
Tensile Strength	318 kPa
Diameter	0.05 mm

3 RESULTS AND DISCUSSION

3.1 *Experiments on RCBDW aggregate*

As mentioned earlier, recycled aggregate from crushed building demolition waste (RCBDW aggregate) supplied by Canberra Concrete Recyclers Ltd. was investigated for potential use as pavement base and/or sub-base. The particle size distribution (PSD) of RCBDW aggregate determined from laboratory samples (according to ASTM D422-63 and C136-93 methods) is compared with the Standard specifications of typical Sub-base materials in Fig. 2. According to the Unified Soil Classification (USC) method, the RCBDW aggregate was classified as GW, which is a well-graded gravel or gravel-sand mixture with little or no fines. It was classified as A-1-a, i.e. a well-graded sand and gravel, according to the AASHTO method (see Table 2) and consisted reasonably good compactability characteristics. Under the general guidelines of AASHTO, the material classification appears acceptable for the base and/or sub-base courses of pavements but further checks against specifications for different grades of aggregate need to be carried out (e.g., Asphalt Institute, 1970 and Bowles, 1992).

According to the PSD, the RCBDW aggregate meets the requirements for Grading B, which is acceptable as a Class 1 sub-base material according to NSW-RTA Specifications (see Fig. 2). This RCBDW aggregate failed to meet sub-base Grading A requirements due to lack of material smaller than 19.0 mm. In order to meet base layer grading, the grading should be modified such that more than 95% of the material passes through 19 mm sieve. At present only 83% of the material is below this size.

Tests conducted to study the foreign material present in RCBDW aggregate indicated significant variability within a single product (see Table 3). These results indicate that RCBDW aggregate failed to meet the requirements of NSW-RTA (New South Wales – Road and Traffic Authority, Australia) QA Specification 3051. In all three tests, the brick content ranged from 1.5 to 3.6 and was well over the percentage allowable for low density or crushable materials. Also, in Test 1, the wood content was at least double that allowed in the Specification. It was four times that allowed by the RTA specification if traffic loading was greater than 10^6 equivalent standard axles (ESAs) for using the material as a base.

Table 2 Summary of results for crushed building demolition waste

Aggregate source	Optimum Moisture content (%)	Max. dry density (kN/m^3)	CBR – 2.5 mm penetration (%)	CBR – 5 mm penetration (%)
RCBDW	13.1	18.2	14	24

The mechanical characteristics of RCBDW aggregate was assessed through CBR testing and the result summarised in Table 1. It is general practice to take the CBR for 5 mm penetration in pavement design if it is greater than the CBR for 2.5 mm penetration (e.g., Bowles, 1992). However, at least one subsequent test must be carried out to confirm this result and this was satisfied for the CBR results reported in this paper. Consequently, the CBR of RCBDW aggregate was 24 and this is within the 20 to 50 range for materials generally accepted for pavement base/sub base construction (Asphalt Institute, 1970 and Bowles, 1992).

Table 3 Foreign Material content for Recycled Building Material and comparison with NSW-RTA QA Specification 3051

Foreign Material	Test Results (determined in accordance to NSW RTA Test Method T276)			Design Traffic, N	Maximum Limit specified by NSW –RTA (% by Mass)	
	* Test 1	* Test 2	* Test 3		Base	Sub-base
Metal, Glass, Asphalt, Stone, Ceramics, Slag (other than blast furnace slag)	6.8	7.7	2.8	$N \geq 10^6$	3.0	5.0
				$N \leq 10^6$	5.0	5.0
Plaster, Clay Lumps and other Friable Material	1.5	3.6	2.1	$N \geq 10^6$	0.2	1.0
				$N \leq 10^6$	0.5	1.0
Rubber, Plastic, Bitumen, Cloth, Paint, Paper, Wood and other Vegetable Matter	0.4	0.2	-	$N \geq 10^6$	0.1	0.2
				$N \leq 10^6$	0.2	0.2

* Materials for testing were obtained from Canberra Concrete Recyclers Ltd.

3.2 *Characteristics of fibre reinforced RCBDW aggregate*

As stated previously, there has been no documented research on RCBDW aggregate stabilised by fibre reinforcement for use as a pavement base or sub-base. A preliminary assessment of the effect of fibre reinforcement was made from Standard Proctor compaction tests (i.e., moisture-density relationship using ASTM D698-91) on RCBDW aggregate with different percent of fibre addition (see Fig. 3). Increased proportions of fibres resulted in a decrease (of approximately 15%) in maximum dry density (MDD) and an increase in the optimum moisture content (OMC). These results are in agreement with Hoare (1979) who noted the inclusion of reinforcement provides some resistance to compaction. The OMC didn't deviate to any great extent from that of the original material, a maximum increase in OMC of about 2% for adding up to 2% fibre, and Guido et al. (1995) also made similar observations. Consequently, the OMC of the original material, (i.e., 11.3% moisture content), was used in preparing the samples for all other testing with different fibre content percentages reported in this paper. This allows simplification of test procedures and ensures a commonality between tests with different fibre content.

To assess the effects of mixing fibre reinforcement, CBR tests were carried out (in accordance to Australian Standard AS 1289, 1977-1996) on RCBDW aggregate samples mixed with different percentages of fibre. As seen in Fig. 4, the CBR decreased with increasing fibre content apparently due to lack of bonding/interaction between fibre reinforcement and RCBDW aggregate particles. However the resilient modulus increased significantly for increasing percent of fibre (sample preparation and testing details are presented later) suggesting that fibre reinforcement could enhance the resilient characteristics of the aggregate and its potential for use in pavements.

To enhance the interaction between the fibre reinforcement and aggregate particles, small percent of (i.e., 3%) cement was added to the fibres first and then mixed with the RCBDW aggregate for the subsequent tests. However, the overall moisture content was kept the same at about 11.3%. To make meaningful comparisons, the RCBDW aggregate treated with 3% cement only was also tested. All the results of tests reported hereafter were conducted after 7 days of curing. Two types of curing was also investigated in this study, hereafter referred as "simple" and

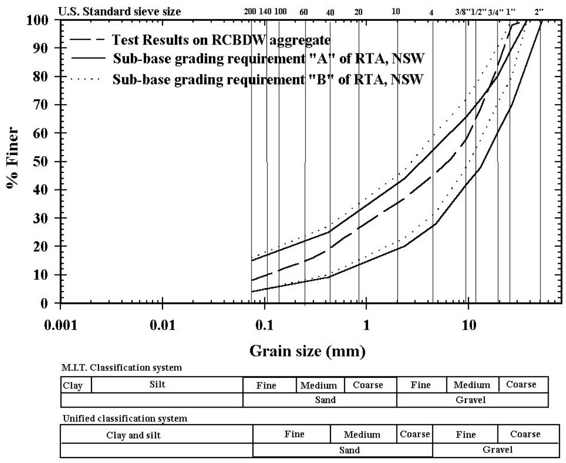

Fig. 2 PSD of RCBDW aggregate and comparison with specifications

"advanced" curing respectively. In the simple curing, the compacted sample was wrapped with wet cloth, placed in a plastic bag and allowed to cure in the humidity room at 23 C. In the advanced (or accelerated) curing, the compacted sample was wrapped in wet newspaper, sealed in aluminium foil and cured in an oven at 65°C.

The mechanical characteristics of fibre reinforced soils are often assessed through UCS testing (e.g., Santoni et al., 2001) primarily because of its simplicity, availability of equipment and low cost. Therefore, in addition to cyclic triaxial testing, UCS testing was also conducted (in accordance to ASTM D2166 – 1991) on samples of RCBDW aggregate treated with varying fibre contents, i.e., from 0% to 0.5% by dry mass, and the results are summarised in Fig. 5. These tests were carried out on 100 mm diameter by 200 mm high samples prepared under standard CBR compaction, compacted at (or near) optimum moisture content (i.e., at about 11.3% moisture). Cyclic triaxial tests were also conducted on similar samples to determine the resilient modulus and permanent deformation characteristics. These tests were performed under 42 kPa constant cell pressure up to a deviator stress of 378 kPa using a trapezoidal type loading pattern at 1 Hz frequency in accordance to the Australian Standard (AS

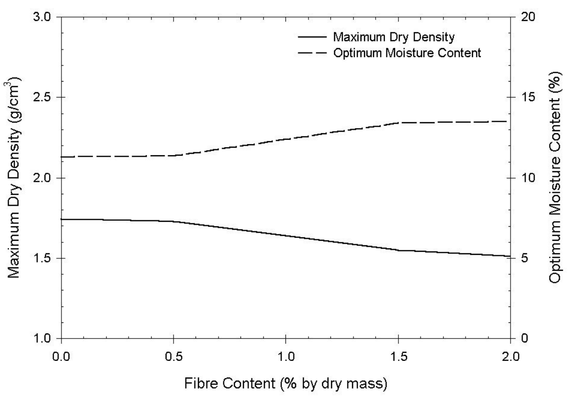

Fig. 3 Variations of MDD and OMC with fibre content (0% cement)

1289.6.8.1) up to 2000 cycles. A summary of these results shown in Fig. 5 indicate that the resilient modulus of RCBDW aggregate could be increased slightly from 520 MPa to 570 MPa,

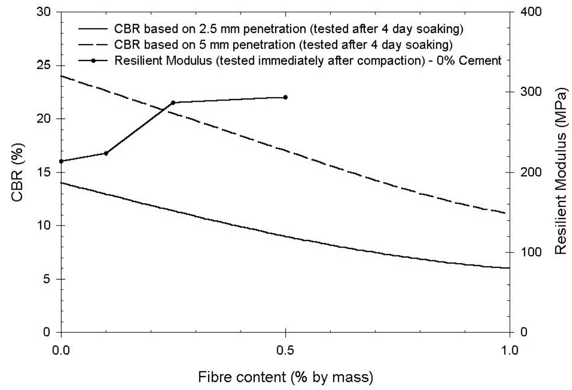

Fig. 4 Variations of CBR and resilient modulus with fibre content (0% cement)

an increase of about 10%, by treating the RCBDW aggregate with about 0.25% fibre in addition to that of 3% cement.

The results further indicate that for the plain material (i.e., 0% cement and 0% fibre) under simple curing yields higher resilient modulus for the RCBDW aggregate compared to that from advanced curing. However, UCS showed an opposite trend of higher value for advanced curing compared to simple curing. For 0.25% fibre addition together with 3% cement, the advanced curing yielded higher resilient modulus than simple curing but the simple curing gave higher UCS around this fibre content range. This observation suggests that UCS test may not be reliably used to estimate the resilient modulus of RCBDW aggregate particularly when fibre reinforcement and cement are used to stabilise it. This finding is contrary to that reported by Gnanendran et al. (2002) of the suitability of UCS for estimating resilient modulus of lime stabilised RCBDW aggregate from UCS test results. This difference is attributed to the difference in the interaction mechanisms between fibre plus cement and aggregate compared to that of lime and aggregate as well as the influence of loading pattern and curing methods on the material characteristics.

The strain due to permanent deformation in 2000 cycles of loading in cyclic triaxial testing decreased from about 1.1% to 0.5% when the RCBDW aggregate is stabilised with 0.25% fibre plus 3% cement compared to that of 3% cement only (see Fig. 6). This translates to a reduction in permanent deformation of over 100% when fibre reinforcement is used, apparently due to enhanced reinforcing effect. Moreover, the addition of fibre alone also resulted in a reduction in the permanent strain; i.e., the

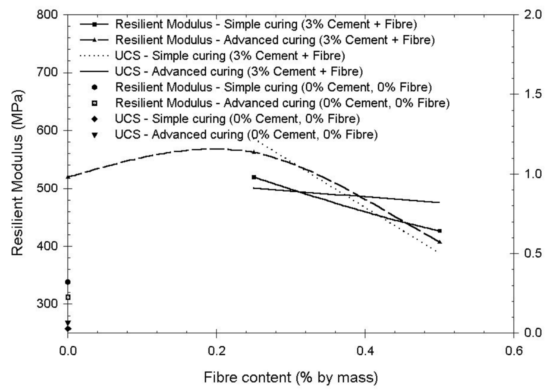

Fig. 5 Variations of mean resilient modulus and UCS with fibre content

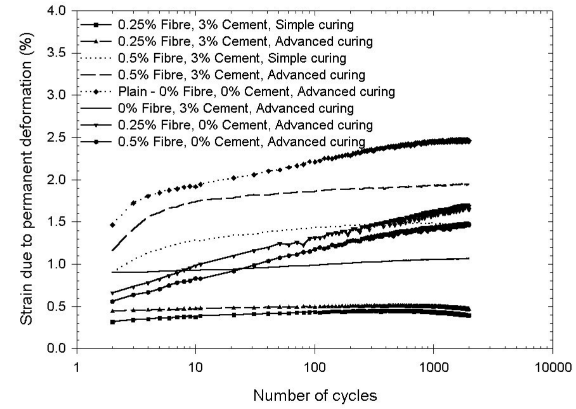

Fig. 6 Accumulation of strain due to permanent deformation with number of cycles

permanent strain in 2000 cycles decreased from 2.5% for the plain RCBDW aggregate to 1.7% and 1.5% when reinforced with 0.25% and 0.5% fibre respectively. This would translate into a reduction in the accumulation of permanent deformation by 32% and 40% respectively for 0.25% and 0.5% fibre reinforcement. Thus, the addition of fibre either alone or with cement would enhance the pavement's ability to resist rutting despite the earlier observation that the use of fibre alone decreases the resilient modulus (or stiffness).

It is further noted that advanced curing resulted in a significantly higher permanent strain compared to that of simple curing all through the 2000 cycles of testing when reinforced with 0.25% and 0.5% fibre together with 3% cement. However, the resilient modulus results didn't show a consistent pattern of comparison between the two curing methods (i.e., advanced curing gave higher resilient modulus when reinforced with 0.25% fibre + 3% cement compared to that of simple curing but the trend reversed when 0.5% fibre reinforcement + 3% cement was used).

4 SUMMARY AND CONCLUSIONS

The recycled aggregate from crushed building demolition waste (RCBDW) was classified as GW and A-1-a(0) according to the USC and AASHTO methods respectively and found to possess reasonably good compactability characteristics. But it contained significant foreign particles such as brick and wooden pieces and failed to meet the requirements for acceptance as base and sub base materials for pavement construction.

The potential of using RCBDW aggregate by stabilsing it with fibre and fibre plus cement for the construction of road/pavement sub base and/or base was investigated experimentally and the results reported. A fibrillated polypropylene type fibre, easily available in Australia, was used in this investigation. In addition to traditional properties such as CBR and unconfined compressive strength (UCS), the resilient modulus and the accumulation of permanent strain under cyclic triaxial testing conditions were also studied not only for RCBDW aggregate but also for the stabilised material. The study investigated the effects of two types of curing methods also on the stabilised and unstabilised material and the results compared in this paper.

This investigation suggests that the CBR and resilient modulus of the RCBDW aggregate could not be improved by the addition of the particular type of fibre alone. However, its resilient modulus could be improved slightly (by about 10%) and the strain due to permanent deformation decreased by over 100% by reinforcing it with about 0.25% fibre plus 3% cement compared to that of 3% cement alone. The addition of fibre alone also resulted in a reduction in the permanent strain; i.e., the permanent strain in 2000 cycles decreased by about 32% and 40% compared to that of the RCBDW aggregate when reinforced with 0.25% and 0.5% fibre respectively. Thus, the addition of fibre either alone or with cement would enhance the pavement's ability to resist rutting despite the earlier observation that the use of fibre alone does not improve the resilient modulus (or stiffness).

Although further testing is continuing, the results obtained so far suggest that UCS may not be used reliably to estimate the resilient modulus of the RCBDW aggregate stabilised with fibre plus cement. This is apparently due to the differences in the interaction mechanisms between fibre plus cement and aggregate as well as the influence of loading patterns and curing methods on test results.

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