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Waste Rubber Aggregates for Use in Asphalts: A Laboratory Study

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Abstract

The paper presents laboratory test results on bituminous mixtures containing upgraded waste rubber coarse and fine aggregates compared with control mixtures.

The mixtures incorporating rubber and fine waste rubber aggregates where designed as potential playground surfaces and contain higher levels of bitumen binder than the standard mix. The combined influence of the binder content and alternative aggregates is to reduce the stiffness of the asphalt and make the pavement suitable for children to play and walk on safely.

The rubber and fine waste rubber aggregates were pretreated using LJMU additives© for improving the bonding/ adhesion between the waste aggregates and the bituminous binders and to reduce the swelling of these materials when they come in contact with bitumen at high temperatures.

Repeated load axial and repeated load indirect tensile tests were performed on the bituminous mixtures.

The test results are encouraging, showing significant improvements in the bond strength between the aforementioned waste aggregates and bitumen in the tested mixtures. This offers the prospect of using these materials in low traffic load bituminous pavements *e.g.* school playgrounds, pathways, leisure areas etc. The applications of such materials in high traffic load bituminous pavements should be the subject of further investigations.

Keywords

Waste rubber aggregates, Fine rubber aggregates, Bituminous pavements

1. Introduction

The use of rubber waste aggregates in asphalt applications requires positive response to the following; the achievement of suitable engineering performance, cost effective, environmentally secure for present day and future applications, and have an acceptable effects on worker health and safety.

The number of scrap tyres generated each year is immense and raises a number of important and difficult issues regarding their use. To date, more than 100 different uses have been found for them ranging from burning as a fuel source through to landfill. In terms of their use in asphalt, the situation varies widely between reported successes and failures (Amjad *et al*., 1999; Child, 2000; Zoorob, 2000). Many benefits from using recycled rubber are claimed, although the evidence is variable.

The main disadvantages of using rubber in asphaltic products are:

- The high initial cost of the product
- Increased processing costs.
- In environmental terms the view that "Using the currently available information, we find there is no compelling evidence that the use of asphalt pavement containing recycled rubber substantially increases the threat to human health or the environment as compared to threats associated with conventional asphalt pavements" (FHWA, 1993) is not universally accepted.
- The tyre-modified asphaltic mixtures are not cost-effective and generally cost more than 50 per cent more than conventional materials.

Today, in US, the rubber-modified asphalt is used primarily in California and Arizona, where more than 400 million pounds (in weight) of scrap tyre rubber is consumed in those two markets (equivalent to just over 2 million scrap tyres).

In the UK, their usage in asphalt applications has been rather limited owing to increased plant and production costs and concerns over whether there is a demonstrated improvement in actual road performance. However, there are still some environmental concerns where tyres are used in locations close to watercourses or in 'below water table' situations and they may be summed up as: the uncertainty about the long term effects of buried tyres on ground water sources and the leaching of minute quantities of chemicals (i.e. pollutants) (Hassan *et al*., 2004).

Of course, leachate studies should be carried out on both scrap tyre rubber and recycled plastic used in road building.

Clearly, from the review, the number of rubber waste products seems high; very few of them have found any real market volume in highway applications. The majority of their uses are alternative materials to substitute for, or use in addition to, primary crushed aggregates and fillers. Scrap tyres can suffer from variable performance, quality problems and recyclability issues.

2. Bituminous Products Contain Rubberised Bitumen

A range of bituminous products contain rubberised bitumen has been developed and tried in different places worldwide in the past 25 years (Child, 2000; Robin and Schroeder, 1994; Hassan *et al*., 2004). The aim of the majority of these trials have been carried out to assess the effect of fine rubber modified bitumen on the properties of the bituminous materials, and the use of rubber as a substitute for aggregate in less detailed research activities. The following materials are produced and used for reducing the noise generated between moving traffic and road surface.

Colsoft: is a surface course that has been applied on urban streets, by-passes and motorways in Europe. The surfacing is a 6mm or 10mm gap graded material that incorporates small particle crumb rubber and typically provides a reduction in noise of around 5dB. It is produced in hot-mix asphalt plants and is paver-laid. Further details of the mixture can be obtained from (www.colas.co.uk/508.htm).

Highways Agency Pavement Engineering Group (Child, 2000) reported a trial of Colsoft, the ‘Quiet Surface Course’’ laid in Surrey. UK. Comparing Colsoft with other thin surfacing products laid indicates that it provides a very quiet surfacing although texture depth is relatively low.

Results of tested samples from the original trial sites indicated that resistance to permanent deformation, measured by wheel tracking, would be suitable for local urban sites. The stiffness modulus of 0.94GPa at this site is lower than other proprietary thin surfacing materials which are usually in the range 1.15 to

3.34GPa. The material is still being monitored since 2003 and appears to be performing satisfactorily.

Playground surfacing: The main two types of playground surfacing are i) Playgrounds with climbing frames, slides and other apparatus, and ii) School playgrounds. At the present although both categories may have important commercial applications category (ii) seems to provide a more likely area for commercial success.

Playgrounds Specifications relating to playground surfacing deal principally with aspects of health and safety, as the loading criteria associated with highways is not a consideration, unless the playground is subject to delivery of refuse collection vehicles, for instance. The most important specification to be adhered to for playground surfacing is BS EN 1177 (1998) 'Impact absorbing playground surfacing-Safety requirements and test methods'. The most important aspect in BS EN 1177 (1998) is the specification of surfacing that limits the likelihood of fatalities from head injuries after falls in excess of 600mm. This is done by specifying that a surfacing must provide a Head Injury Criterion (HIC) of 1000 or less. The test method for determining HIC consists of dropping a 'head form' fitted with accelerometers and equipment to measure, record and display the acceleration and time duration of each impact. HIC values are calculated using a formula relating HIC to acceleration and time intervals. The reported value is the drop height at which a HIC of 1000 or less is achieved.

School playgrounds are typically consist of a 20-30 mm surface course of 6 mm dense bitumen macadam (DBM), 40 mm DBM binder course on at least 150mm Type 1 sub-base, normally constructed to standard footway or car park designs. The School Building Design Unit (DFES) and the Health and Safety Officer from a local authority are looking for a playground more child-friendly surface. Although, rubberised surfacing have been considered for some time, but have been found to be too expensive, both in initial construction and in whole life cost terms. It might be the case that if an asphalt mixture could be found that reduced the hardness of the surfacing 'significantly' by simply substituting some of the natural aggregate with rubber waste aggregates; it would be welcomed by Education Authorities.

Rubberised bituminous mixtures suffer from lack of bonding between the rubber aggregates and binders and thus less design life. This phenomenon arise from the fact that the rubber aggregates swell when become in contact with the bitumen binders at elevated temperature and remove the light molecules from the binder leaving the heavy molecules in the binder mastic holding the aggregates in the pavement mixtures. Heavy molecules with time become brittles and the aggregates may be removed after short time of opining the pavement to services. In this study the waste rubber aggregates were pre-treated using JMU additives© for improving the bonding/adhesion between the waste aggregates and the asphaltic binders and to reduce swelling of the rubber material.

3. Materials and Testing

The investigation into the possible use of rubber in asphalt in playground surface pavement was carried out in two main phases: (1) development of trial mixtures by Liverpool John Moores University (LJMU), and (2) testing a trial section at a playground site to evaluate and confirm the characteristics of the asphalt mixtures developed in phase (1). This section gives a brief description of the materials and a summary of the test results.

A medium graded surface course (MGSC) mixture was selected following testing of the combinations of binder and aggregate replacement shown in Table 1. Standard mixtures for product development were tested. In addition mixtures incorporating a proprietary modifier were tested to see if improved properties could be gained to contribute to future product development.

Table 1: Medium Graded Surface Course MGSC Mixtures

Mixtures	Type of Binder[1, 2]	% Binder content (of total mass)	% Rubber Aggregates (by aggregate mass)
Mix A: control mix	A	5.4	0
Mix AR: Mix A + rubber aggregates	A	9.5	8
Mix C: control	C	4.5	0
Mix CR :Mix C + rubber aggregates	C	9.5	8
Mix CMR: Mix CR + modified binder	Modified Binder C	9.5	8

Note 1: The additive used to modify the binders is a proprietary material developed by LJMU.
Note 2: Bitumen A: 45 pen, R&B 85 deg C and mixing temperature 190 deg C
Bitumen C: 125 pen R&B 42 deg C and mixing temperature 160 deg C.

The findings, relative to a 'typical' BS4987 mixture, are summarised in the following sections.

4. Stiffness and Deformation Measurements

1. Repeated load indirect tensile stiffness test results are used to determine the indirect tensile stiffness modulus of asphalts containing primary and rubber aggregates carried out in accordance with the method set out in British Standard DD 213:1993.

As the test is non-destructive, repeated load indirect tensile tests were performed on the 0-6 mm MGSC specimens first so the specimens could be retested later with repeated load axial test for the measurement of axial deformation (BS-DD 213:1993). Both tests were carried out on 100 mm diameter specimens produced in the laboratory and the testing temperature was 20°C, as specified in DD 213:1993.

The mixtures incorporating 8 % rubber aggregates (by aggregate mass) where designed as potential playground surfaces and contain 9.5 % binder content (of total mass). This is a higher level of bitumen binder than the 5.4 % binder content in the standard control mix which is specified to produce a play ground mixture preferably exhibits low stiffness. The combined influence of the binder content and alternative aggregates is shown in Figure 1, where the reduction in the stiffness of the asphalt by up to 87% for the 125 pen material and 90% for the 45 pen material is very predominant. The stiffness of asphalt with rubber aggregates can be more than doubled by the inclusion of bitumen modified with the LJMU additive as can be seen in Figure 1, which is higher than the rubberised mixture containing the hard bitumen.

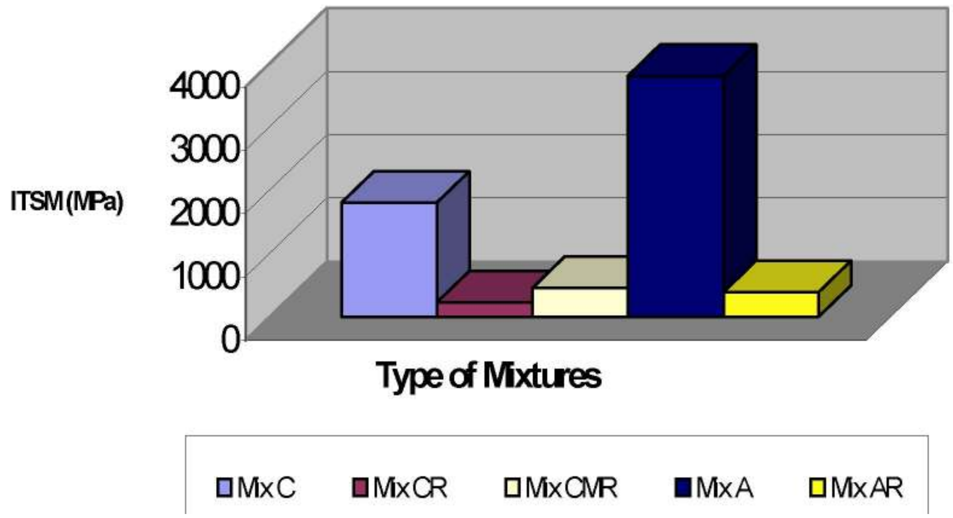

Figure 1: Indirect Tensile Stiffness Modulus for all Mixtures

Figure 1 shows that asphalts with untreated rubber waste aggregates display significant reductions in stiffness. In terms of actual stiffness moduli, this represents a reduction of 1573 MPa for mixture CR, and 3408 MPa for mixture AR.

When comparing the results of the mixtures containing treated rubber, CMR with mixtures CR containing untreated rubber, it can be seen that the anticipated improvement in stiffness with bonding improvement between the treated waste aggregates and bitumen occurs as expected. Mixture CR exhibits a stiffness of 227 MPa whilst mixture CMR exhibits a stiffness modulus of 458 MPa, an improvement of 101.8%. In Figure 1, mixture A with untreated waste aggregates shows a reduction in stiffness of 90% compared with the stiffness of mixture A.

To investigate the mixes containing waste aggregates sensitivity to water, samples containing waste plastic aggregates were subjected to water immersion test first (BS-DD216:1996, BBA 2000). The samples were then tested using the NAT test for the measurement of the retained stiffness (conditioned stiffness). The unconditioned and conditioned stiffness of samples made from mixtures C, CR, CMR were calculated in accordance with BS DD 213:199, the standard test is 3 cycles only and plotted in Figure 2 which shows that a little or insignificant reduction in mixes C and CR is reported. Interestingly the CMR conditioned mixtures showed a significant increase in their stiffness indicating that the treatment of the rubber with the LJMU additives improved the bonding adhesion between the treated waste rubber aggregates and the binder and thus increase the stiffness of the materials tested.

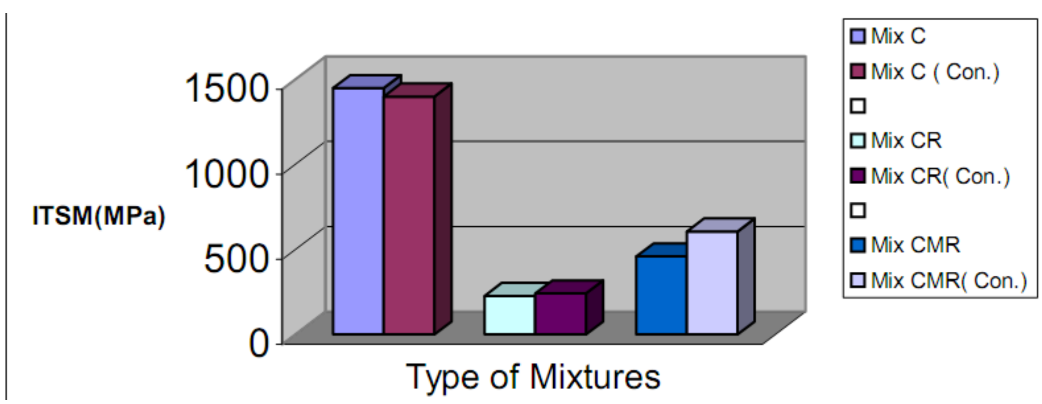

Figure 2: Conditioned and Unconditioned Indirect Tensile Stiffness Modulus

2. The repeated load axial deformation test (RLAT) has been used extensively in the past to measure resistance to permanent deformation, both in mixture design and for retrospective studies, Brown *et al.* (1993), and for the purpose of this study, it was considered important to rank the MGSC samples showing the degree of change in the permanent deformation resistance of mixtures containing 8% (by total weight of aggregates) of rubber waste aggregates compared with control mixtures. For this reason, RLAT in accordance with DD 226:1996 was chosen to achieve this aim.

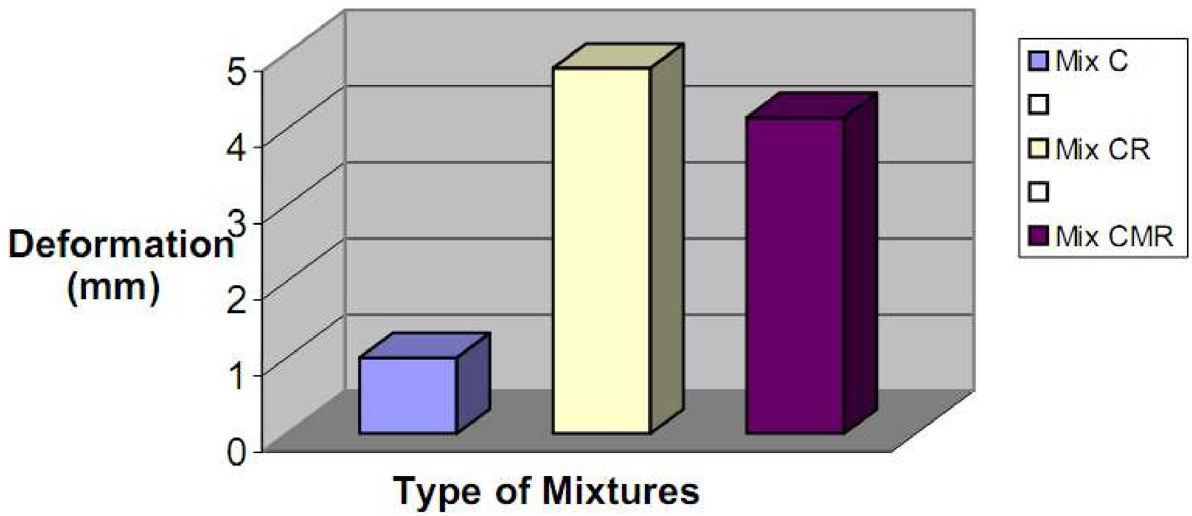

Figure 3: Resistance to Deformation (mm) Type of Mixtures

The axial deformation of the asphalt samples containing rubber aggregates shows significant increase in their deformation; however the treated waste rubber aggregates exhibited less deformation than the mixtures containing untreated rubber aggregates. The CMR samples show an improvement in percentage terms of axial deformation of 25% compared to the CR samples.

The improvement in the resistance to axial deformation for asphalt mixtures containing treated waste aggregates is related to the improvement in the mixtures deformation resistance at the interface between the aggregates and the bitumen and the improved surface texture of the treated waste plastic and rubber aggregates.

5. Conclusions

1. The addition of waste tyre crumb rubber aggregates to the 0-6 mm size medium graded surface course had an adverse effect on the mixture properties (volumetric, stiffness, durability and resistance to permanent deformations).

2. The stiffness of asphalts improved significantly with the use of waste aggregates upgraded by using JMU additives©. Based on the number of tests performed, retained stiffness values either remained the same or increased slightly due to the addition of upgraded rubber crumb waste aggregates.

3. The research work indicates that treated waste rubber aggregates have adequate bonding and/or adhesion characteristics to produce the mechanical and chemical properties required for successful playground asphalt. The JMU additive technology/material performed well during testing, proving itself to be amenable to bonding with bitumen, and very resistant to the degrading effect of the ingress of water (based on the number of tests covered in this research work).

6. Acknowledgements

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