Mechanical Properties of Hydraulically Bound Road Foundation Materials Containing High Volume of Limestone and Steel Slag Waste Dusts

H. Al Nageim

Professor of Structural Engineering, Liverpool John Moores University, UK.

P. Vasileiou

Highway Engineer, Colas ltd, UK

ABSTRACT: The paper presents laboratory test results on hydraulically bound road foundation materials containing high volume of; limestone, steel slag (SS) and granulated blast furnace slag (GBS) dust compared with Type 1 sub base materials normally used by road engineers in the UK as a foundation layer with or without capping. The mixtures incorporating waste dusts were designed as potential hydraulically bound road pavement foundation layer and contain in addition to the dust in the control sub base the following percentage of dust: i) 20% limestone dust, ii) 20% SS dust, iii) 20% limestone dust + 5% GBS and iv)20% SS dust + 5% GBS.

The size of the dust aggregates range from 0-4mm. The addition of the wastes dust was to enhance the stiffness of the road foundation materials, save primary aggregates and hence reduce the cost of road construction.

The unbound and lightly bound materials resilient modulus were predicted using triaxial repeated load tensile tests according to the current European code of practice and compared with type 1 sub base materials at their optimum water contents.

The test results show outstanding increase in the resilient modulus of mixes containing the percentage of dust mentioned in items (iii) and (iv) above. This improvement was found due to the increase in the strength of the mortar paste between the content of these mixtures, namely; waste aggregates dust and primary aggregates. This finding offers the prospect of using these materials in road unbound foundation materials to reduce the use of primary aggregates and thus minimizing the cost of roads and highways construction.

KEYWORDS: Road sub-base, unbound road foundation materials, steel slag dust, limestone waste dust

.INTRODUCTION: ROAD FOUNDATION MATERIALS

The three main types of pavements; i) rigid or concrete pavement, ii) rigid composite pavements and iii) flexible pavements are shown in figure 1 below.

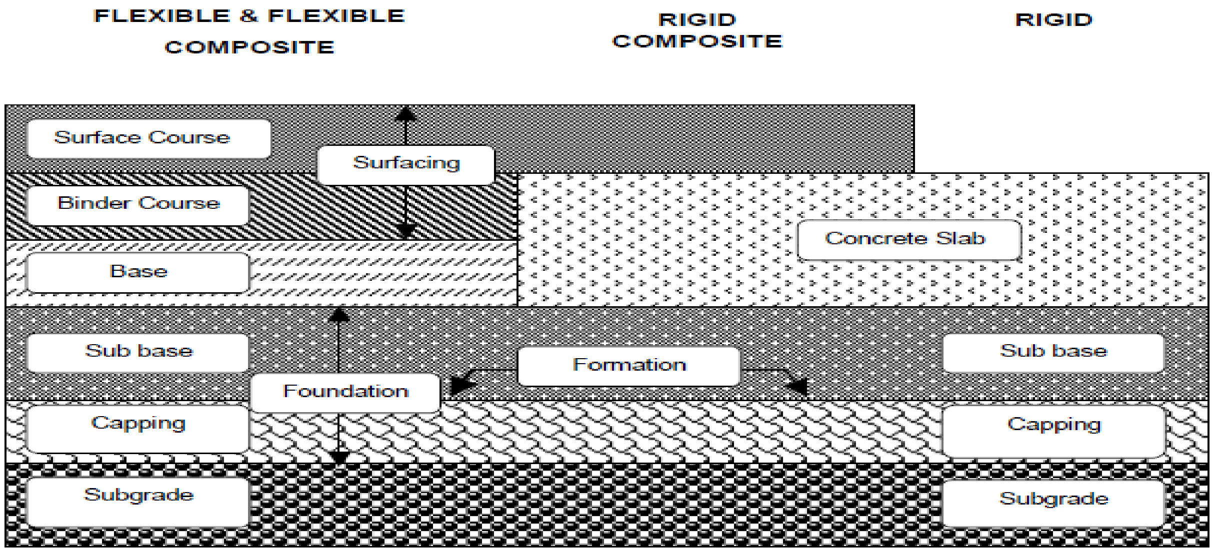


Figure 1. Different Pavements and Their Foundations (Wanab, Y. 2005)

The upper layers of pavements are made from materials of stronger properties where the stresses within these layers are at its highest values due to the direct contact between the material of the upper layers and the loads from moving traffics. However, the lower layers are made from less expensive and weaker materials as they receive less stress from the load applied on the surface of the road.

Pavement layers mechanical properties can vary depending on ground conditions and weather conditions and also the availability and cost of the materials being used. An example of a typical flexible pavement would consist of surface layers, base, formation layers which in turn include sub-base and capping layer if required.

The role of the road foundation layer sometimes called sub base layer or unbound layer within the pavement is to act as a stable platform on which the upper layers of the pavement can be compacted and constructed. The unbound layer should also be permeable and non-frost susceptible and they should operate as a frost protection layer, insulating the sub grade against frost attach. Also an unbound layer should spread the traffic load to reduce stress on the underlying pavement layer and the sub grade, thus preventing overstress and rutting in the sub grade.

The performance of a material depends on where it exists in the pavement structure. Traffic-induced stress is highest on the road surface and diminishes with depth according to the load-spreading capacity of the different materials [1-4].

In some cases, where soil had a very high load bearing capacity or a high California Bearing Ration (CBR) value, there might be no need for any formation layers to support the sub-base at all or in the other extreme there might be a necessity to include a layer of hardcore or rubble under the sub-base called a capping layer. The depth of this capping layer is dictated by the CBR value of the sub- grade or formation level and the depth and mechanical properties of the sub base.

In recent years with greater global awareness and of the effect human beings are having on the environment, there has been a greater emphasis within all industries including the road construction industry to introduce the concept of recycling and the use of by-product materials in road base such as steel slag furnace, steel slag and limestone waste dusts [5-7].

The use of waste materials in the construction of pavements foundation has benefits in not only reducing the amount of waste materials requiring disposal but can provide construction materials with good mechanical properties and significant savings over new materials. The use of these materials can actually provide value to what was once a costly disposal problem.

The aim of this work is conduct laboratory tests on unbound and lightly hydraulically bound road foundation materials containing high volume of; limestone, steel slag (SS) and granulated blast furnace slag (GBS) dust compared with Type 1 sub base materials normally used by road engineers in the UK as a foundation layer with or without capping. The mixtures incorporating waste dusts were designed as potential lightly hydraulically bound road pavement foundation layer and contain in addition to the fines in the control sub base the following percentage of dust:

i) 20% limestone dust
ii) 20% limestone dust + 5% GBS
iii) 20% Steel Slag (SS) dust
iv) 20% Steel Slag (SS) + 5% GBS dust

The size of the dust aggregates range from 0-4mm. The addition of the wastes dust was to enhance the stiffness of the road foundation materials, save primary aggregates and hence reduce the cost of road construction.

2 SUB-BASE MATERIALS AND TESTING FOR RESILIENT MODULUS

With the overall aim of this study being to make the initial results for establishing of the early stage mechanical behavior of road base materials containing high level of ; i) limestone dust and ii) steel slag (SS) waste dust with and without the addition of GBS. Five triaxial samples from each of the mixes shown in Table 1 were prepared according to the British Standard, BS. EN 13286-1:2003 [8] and BS. EN 13286-7: 2004 [9] and tested for the evaluation of Resilient Modulus, Mr, using the triaxial facility at Liverpool John Moores University. Samples have been compacted in three equal layers at their optimum moisture contents directly into 150 mm diameter cylindrical moulds with a height of 300 mm.

Table 1. Material types and mix descriptions

Material type/ Mix No.	Mix descriptions
Mix 1	Stancombe*, Limestones type 1: control mix
Mix 2	Mix 1+ 20% Limestone dust (L)
Mix 3	90BFS /10 SS control mix type 1 + 20% SS dust
Mix 4	Mix 1+ 20% Limestone dust + 5% GBS
Mix 5	Mix 3 + 20% SS dust + 5% GBS

* Stancombe: Primary limestone aggregates used for road base materials in UK

3 SAMPLE PREPARATIONS AND TESTING PROCEDURES

The BS EN 13286-4: 2003 Vibrating Hammer method has been applied for manufacturing the triaxial samples. According to this BS, all the triaxial samples have a diameter larger than 5 times the largest particles size within the materials, and a height twice the diameter of the sample. Since the materials used in this research work were type 1 unbound road base material plus waste dust (4 mm-0.0 mm) as detailed in Table 1 above, with maximum particle size of 20 mm, therefore all the samples were made with a diameter of 150 mm and a depth of 300 mm. To produce uniform density, the samples were compacted into three equal layers at their optimum moisture contents.

For Resilient Modulus (Mr) testing, BS EN 13286-7: 2004 was the standard pattern followed.
In this research work, the testing starts with the following steps;
(i) sample conditioning using high stress level, see Table 2 below.

Table 2. Conditioning stress levels – method B (BS EN 13286-7, 2004).

	Confining stress, σ_3 kPa	Deviator stress, σ_d kPa	
	constant	min	max
High stress level	70	0	340
Low stress level	70	0	200

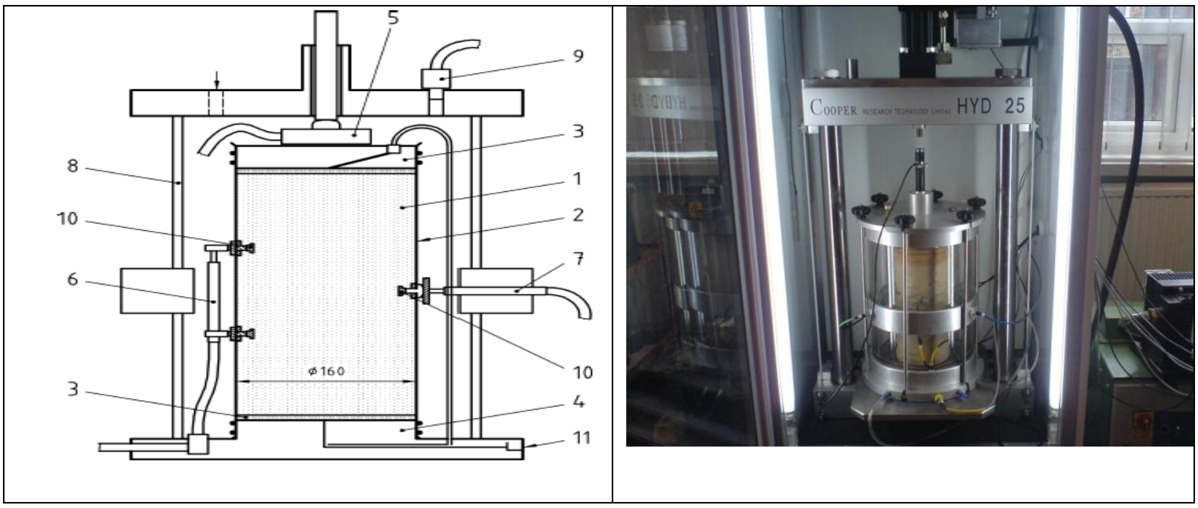
Researchers such as Kendrick, 2004 [3] shows that the high stress level shown in table 2 above is more suitable for unbound road sub-base materials for road and highways carrying heavy traffics, whereas low stress level is suitable for other traffic applications. For a high stress level with a maximum deviatoric stress σ_d=340 kPa, the cyclic deviator stresses are applied according to Table 3 below for 20,000 cycles and thus the applied stress levels should cover the stress range to which the material will be submitted in the field. The conditioning may be stopped at a lesser number of cycles if the permanent axial strain and the resilient modulus become stable. This condition is satisfied if the axial permanent strain rate becomes less than 7 to 10 per cycle and if the rate of variation of the resilient modulus becomes less than 5 kPa per cycle.

Table 3. Stress levels for the resilient behaviour – method B (BS EN 13286-7, 2004).

High stress level			Low stress level		
Confining stress σ_3 kPa	Deviator stress σ_d kPa		Confining stress σ_3 kPa	Deviator stress σ_d kPa	
Constant	Min	Max	Constant	Min	Max
20	0	30	20	0	20
20	0	50	20	0	35
20	0	80	20	0	50
20	0	115	20	0	70
35	0	50	35	0	35
35	0	80	35	0	50
35	0	115	35	0	70
35	0	150	35	0	90
35	0	200	35	0	120
50	0	80	50	0	50
50	0	115	50	0	70
50	0	150	50	0	90
50	0	200	50	0	120
50	0	280	50	0	160
70	0	115	70	0	70
70	0	150	70	0	90
70	0	200	70	0	120
70	0	280	70	0	160
70	0	340	70	0	200
100	0	150	100	0	90
100	0	200	100	0	120
100	0	280	100	0	160
100	0	340	100	0	200

(ii) after the conditioning is completed, the confining stress is reduced to σ_3=20 kPa and allow sufficient time for strain stabilisation (e.g. a rate of change of less than 10–4 per minute). Then, according to the selected maximum stress level, in this research work 340 N/mm^2, the stress levels with confining pressures of 20 kPa to 70 kPa are applied according to Table 3. If higher values of stress σ_3 are likely to occur in the application envisaged for the material, the remaining stress levels in the table 3 can be applied. Each cyclic loading is carried out for 100 cycles, recording the stress and strain values at least from cycle number 90 to cycle number 100. When the stress paths are completed, the specimen is removed from the cell, the measuring system and membrane is taken off, and the water content of the sample is determined using the entire specimen.

Fig. 2 illustrates a schematic sketch of the triaxial cell containing a sample ready for test. Axial linear variable displacement transducers (LVDTs) have been mounted vertically on the sample prior to putting the sample into the cell. Radial LVDTs are already installed on the cell. Having the cell sealed, the LVDTs are connected to the computer and a software receives data and records them according to the BS EN 13286-7:2004 in a file.



1. Specimen, 2. Membrane, 3. Specimen cap, 4. Specimen base,
5. Load cell, 6. Axial linear variable displacement transducer,
7. Radial linear variable displacement transducer,8. Triaxial cell wall,
9. Pressure transducer,10. Studs supporting the displacement transducer,
11. Drainage circuit

Fig. 2: Schematic diagram showing the Triaxial cell and systems for measuring axial and radial displacements using linear variable displacement transducers (BS EN 13286-7, 2004).

4 RESULTS AND DISCUSSION

The Resilient Modulus (Mr) due to the non-linear stress-dependent behaviour of granular materials in road sub-base is determined using the triaxial test. Figs. 3 and 4 show the triaxial testing results of the 5 mixes. All the mixes were manufactured at their optimum moisture contents and stored in the laboratory at a temperature of approximately 20℃ for 28 days before testing.

The figures show the Mr values for the following stress deviators and their corresponding confining pressure; Note, at the two confining pressures values in the table below, the Mr values are the same for their corresponding deviator stress, see Table 3 above.

According to Figures. 3 and 4, the resilient modulus for all the 5 materials tested increases with the increase value of the deviator stress at the confining pressure shown in Table 3 above. Also the addition of 20% waste materials has reduced significantly the Mr value and made these mixes unsuitable for use as unbound material for pavement foundations compared with the control mixes.

In Figure 4 and at deviator stresses of 73 and 125 and where the confining pressure value is 20 N/mm^2 or 35 N/mm^2, the addition of 5% GBS waste dust (all dust used in this research work is made from 0.0-4mm size materials) to the control mix 1 and 90BFS /10 SS control mix2 change the values of Mr at deviator 73 MPa from approximately 250 to1750 MPa and 300 to1000MPa respectively. Whereas these values at deviator 125 changes from 460-2950 MPa and 440- 1350 MPa respectively. The same conclusion held true at deviators 210 and 250 where the confining pressure value is 50MPa or 70 MPa.

This indicates that the value of Mr is a function of both the deviator, the confining pressure and the state of adhesions (cementatious binding of the fine paste in the existence of water at the optimum water content). In the opinion of the authors, the increase in the amount of lime stone dust in the control mix 1 and 2 increases the amount of fines within the mix and thus reduces the aggregates interlocking and this in turn resulted in a decrease of the Mr values.

Table 4 Deviator (N/mm^2) stress and confining pressure.

Deviator stress (N/mm^2)	73	125	170	210	250	310
Confining pressure (N/mm^2)	20, 35	20, 35	35, 50	50, 70	50, 70	70, 100

Adding GBS fine particles within the samples and in the presence of the water at the level of optimum moisture content to which each samples were made activates the fine particles of the limestone dust and SS dust and improve the hydration products which act as a binding agent/paste in the mixes. A closer look at these mixes suggested that they are concrete-like lightly bound road foundation. This has suggested that the limestone and SS dust has reacted with water in the present of the GBS dust which acted as an activator.

In collaboration with our industrial, the reasons behind the increases in the stiffness modulus of the mixes containing GBS fines and other mechanical properties at different ages are under investigations at LJMU using X-Ray diffractions (XRD), Electron Scan Microscopy (ESM), and other normal concrete testing analysis. Initial results of these mixes showed hydration products similar to those generated at early stage of concrete hydrations. This is still under investigation in and the results will be published in another paper in the near future.

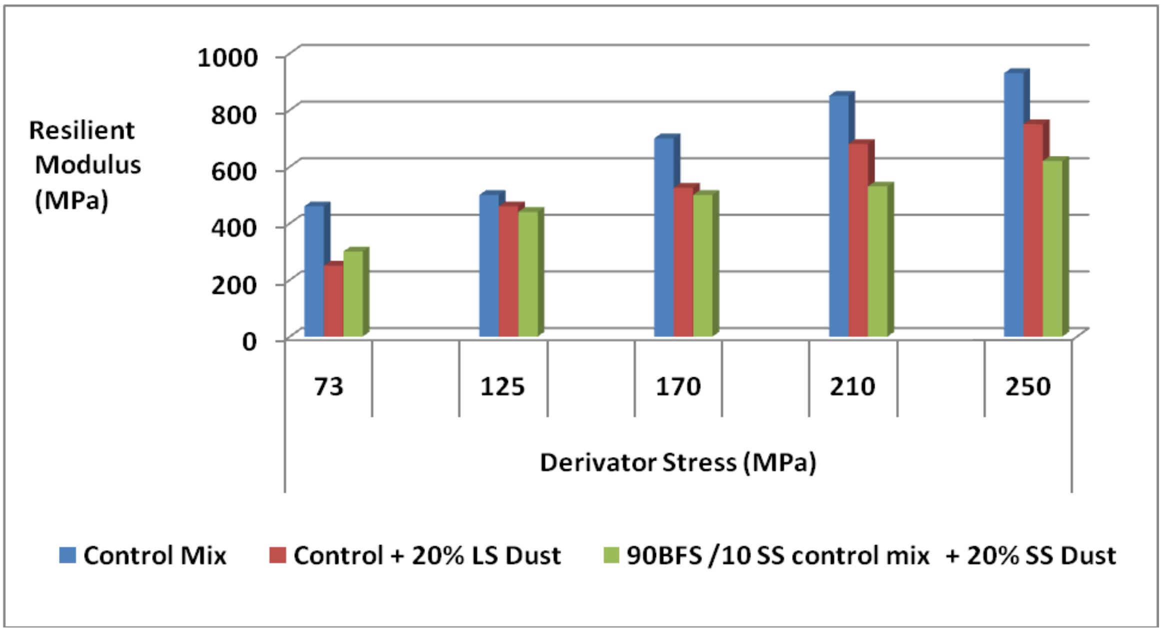


Figure 3. Resilient modulus of control mixes compared with the mixes containing waste dust

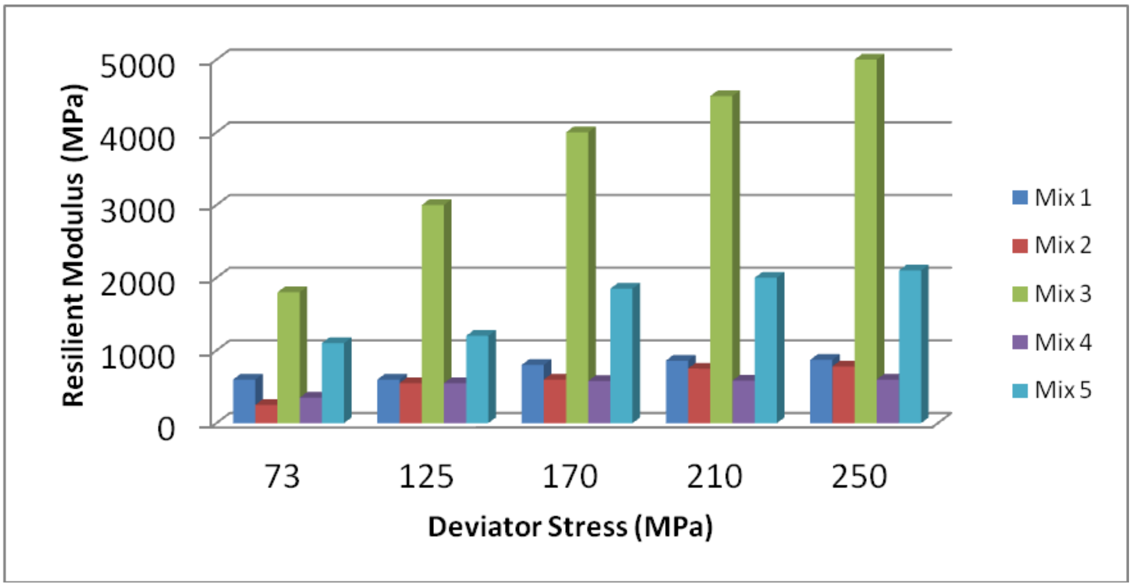


Figure 4. Resilient modulus of control mixes compared with the mixes containing waste dust with and without GBS.

5 CONCLUSIONS

1. The increase in the limestone dust within the tested unbound samples, has reduced the interlocking between the graded aggregate in the mixtures and hence reduced the values of their corresponding Mr values.

2. Background studies reveals that granulated blast furnace slag possess slow and progressive setting and hardening thus has the particularity of binding ability during construction and good early-age mechanical stability.

3. The addition of GBS dust at a percentage of 5% of the total weight of the control mix + 20% Lime stone dust resulted in a significant increase in the mixes' Resilient Modulus, Mr. This conclusion is also true for the BFS 90/10SS control mix containing 20% SS dust. The authors contribute this increase in the Mr values to the increase in the state of dense interlocking status between the coarse and fine aggregates within the mixes and the increase of the "cement-like" hydration products. Further work is currently undertaken by the authors to prove this.

4. When the GBS dust was added to the 90BFS/10SS control mix with 20% SS dust, an outstanding improvement in the values of Mr were achieved, again indicating that the SS has reacted with the rest of the mixes contents and produced bound materials or concrete-like materials.

References

[1] Boyce, J. R.1976. *The Behaviour of a Granular Material Under Repeated Loading*, PhD Thesis, University of Nottingham. UK.

[2] Sweere, G. T. 1990. *Unbound Granular Bases for Roads,* PhD Thesis, Delft University of Technology, The Netherlands.

[3] Kendrick, P. et al. 5th ed. 2004, *Roadwork.* London: Elsevier Niekerk, A. V. 2002. *Mechanical Behaviour and Performance of Granular Bases and Sub-Bases in Pavements,* PhD Thesis, Delft University of Technology, the Netherlands.

[4] Nunes, M. C. 1997. *Enabling the Use of Alternative Materials in Road Construction,* PhD Thesis, University of Nottingham, UK.

[5] Lay, J.2006. A*lternative Aggregates*. LJMU International Conference on Sustainable Aggregates, Pavement Engineering & Asphalt Technology, Feb. 2006.

[6] www.aggregain.org.uk, March 2006.

[7] Dunster, A. 2001. *Information Paper 18/01. Blastfurnace Slag and Steel Slag Their Use as Aggregates*. CRC London.

[8] BS. 1047-1983. *Specification for Air-Cooled Blast Furnace Slag Aggregate for Use in construction*. Sustainable Aggregate Information Service Provided by WRAP www.aggregain.org.uk

[9] BS. EN 13286-1:2003. *Unbound and Hydraulically Bound Mixtures*. Test Methods for Laboratory Reference Density and Water Content. Introduction, General Requirements and Sampling.

[10] BS. EN 13286-7:2004. *Unbound and Hydraulically Bound Mixtures*. Part 7: Cyclic Load Triaxial Test for unbound mixtures.