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Evaluation of Partial Use of Fine Limestone Dust and Steel Slag Waste Aggregates in Road Base Materials

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ABSTRACT

The paper reports the results of a research project on the evaluation of the potential partial use of waste fines limestone dust and steel by-products as alternative aggregates in type 1 road base materials, one major highway construction product. Type 1materials incorporating waste limestone, steel slag (SS), granulated blast furnace slag (GBS), PFA and lime, have been tested. The results showed that the materials containing up to 20% extra limestone dust have no adequate resilient modulus for road use. However when PFA and lime, GBS and SS waste dust have been added to the control mix containing extra 20% waste limestone dust, the lost in the material resilient modulus has been regained and resulted in materials with an acceptable strength for road and highways construction in addition to the fact that there is an adequate and economic supply of the materials.

INTRODUCTION: FLEXIBLE PAVEMENT AND ROAD BASE MATERIALS

Flexible pavement

Figure 1 below, shows the three main types of pavements. These are rigid or concrete pavement, rigid composite pavements and flexible pavements.
Flexible pavement is the most typical of road structure choices in countries like Ireland, Britain and the European countries due to the temperate and weather conditions experienced in these countries.

Flexible and composite pavements give; 1) smoother and more comfortable travelling conditions for the roads and highways users because of the lack of transverse expansion joints, 2) a superior skid resistance and 3) can withstand more ground movement than the rigid pavements.

The upper layers of flexible 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, whereas 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.

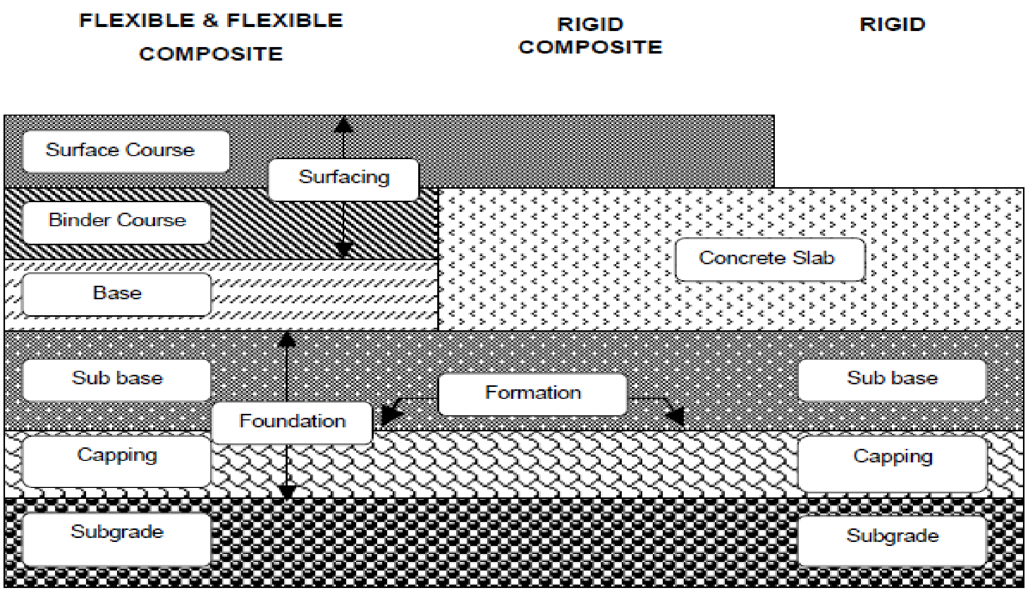

Fig. 1. Different Pavements and Their Foundations (Wanab, Y. 2005)

Flexible pavements 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, road base, formation layers which in turn include sub-base and capping layer if required.

In some cases where soil had a very high load bearing capacity or a high 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 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 included the road and highways construction industry to introduce the concept of re-cycling and the use of by-product materials in road base such as steel slag furnace, steel slag and limestone waste dusts.

Road Base Materials

Road base and sub-base materials normally classed as un-bound materials or bound materials. Unbound materials collectively consist of materials varying in size from fine grains of 1mm in diameter and less up to coarse/stony materials of diameters exceeding several centimetres. Unbound materials are usually used as fill materials as well as capping, road base and sub-base layers of a pavement structures. These types of material are similar to hydraulically bound mixtures in the sense of materials used like type 1 materials-Specification for Highway Works Volume 1 Series 800 and limestone dust but without the binders such as the industrial by-products like PFA or steel slag's hence giving the unbound mixtures less strength than the hydraulically bound mixtures.

Hydraulically bound materials are materials that harden through a process called hydraulic reaction. Such mixtures include cement based mixtures and hydraulically bound mixtures which comprise of slow setting and hardening binders, examples of such mixtures are PFA bound mixtures and steel slag bound mixtures.

Large quantities of industrial by-products are produced every year by chemical and agricultural industries. These materials have dual problems of disposal and health hazards. Among various industrial wastes produced so far, the utilization of by-products such as pulverized fuel ash (PFA), limestone dust, steel slag (SS), granulated blast furnace slag (GBFS), paper process waste (PPW) and others need to be utilized more to save the environment, hence the need for the use of more and more alternative aggregates and by-product materials in the construction industry.

Alternative aggregates can be described as materials which are not naturally obtained from a geological source but can be classed as a waste product or by-product. A summary of potential waste materials used in road construction is shown below.

Table 1. Potential Use of Secondary Materials in Pavement Foundations [Sherwood ,1994]

Material	Capping Layer Unbound	Sub-base Unbound	Cement-Bound Materials
Un-burnt colliery spoils	Low	None	Some
China clay sand	High	Some	High
Slate waste	High	High	Some
Pulverised fuel ash	Low	Low	High
Furnace bottom ash	Some	Some	High
Blast furnace slag	High	High	High
Steel slags	Low	Low	Low
Crushed concrete	High	High	High
Asphalt planings	High	High	Low
Demolition wastes	Some	Some	Low
Municipal incinerator ashes	Some	Some	None
Burnt colliery spoils	High	Some	High
Spent oil shale	High	Some	High

This research project was concentrating on the potential use of waste limestone dust, Fly Ash, GBS, SS waste by-products and lime in road base materials as lightly bound mixtures compared with control type 1 road base and control type 1 with added 20% extra fine limestone dust.

PFA in Road Construction: PFA has been used in road construction for many years and has become an accepted material for such uses as fill material, in concrete, in lean-mix sub-bases and more recently in road base construction as a replacement for the majority of the cement in cement-bound mixtures (CBM). The mixtures that contain pulverised fuel ash and other constituents are commonly known as fly ash bound mixtures (FABM) and are standardised in [BS EN 14227–3, 2004] and are specified in series 800 of the Specification for Highway Works (SHW). These two mixtures (CBM and FABM) are the most commonly used hydraulically-bound mixtures (HBM) for road construction today. In fly ash bound mixtures, fly ash is the main constituent of the binder. The fly ash is mixed with a small percentage of lime and water which causes a pozzolanic reaction to enables the fly ash to harden, giving it adequate stiffness and strength, and gives the road base the desired characteristics that will last for the design life of the pavement.

Blast furnace slag and steel slag: The UK aggregate market is estimated at 270 million tonnes, recycled and secondary 65 millions and demolished and crushed waste of 40 million tonnes [Dunster, 2001]. Unbound road base materials for pavement absorbing more than 135 million tonnes of coarse aggregates. In the last 10 years the rate of using waste and secondary aggregates in unbound road base materials are significantly increased and certain attention being given to the use of Steel Slag (SS) and Blast Furnace Slag (BFS) [www.aggregain.org.uk , March 2006].

It is clear that the partial replacement of primary aggregates with waste crushed rock lime stone dust and Granulated Blast Furnace Slag (GBS) dusts can make a significant contribution towards reducing current reliance on primary aggregate extraction whilst, the available amounts of waste stockpiles will be minimised. Therefore, the impact of this research work is potentially very significant in two ways; first, reducing the extraction of primary aggregates will reduce the environmental impacts of quarrying and any associated social nuisance, and second, developing high value markets for significant waste stream by using alternative aggregates from rock aggregates crushing waste dust, steel slag and blast furnace slag wastes.

Literature review in this area has shown that, steel slag is being used as bound and unbound aggregate in road sub-base; bitumen bound base (road base) and surface (wearing) courses [Arm, 2003]. Applications of BFS include aggregate used for highway capping and sub-base layers; bitumen bound base (road base), binder base and surface wearing courses [Motz & Geisler 2001].

Previous study also has shown that SS and BFS, GBS posses self binding properties [Arm, 2003], *and the early stages development of their stiffens and load carrying capacities properties (when they are used as unbound base materials for highway pavement applications) are not fully explored and understood by their users.*

Recognising the increasing need felt by the unbound and slightly bound pavement engineering practice to advance to more functional specifications for base and sub-base materials, this research application was set up with two aims:

To make the initial results for establishing of the early stage mechanical behaviour of road base materials containing high level of waste crushed rock, SS and GBS dust available in the UK and, to further the understanding of the stress dependent mechanical behaviour of road base containing high volume lime stone dust with GBS hydraulically bound base materials.
All the materials were prepared, manufactured and tested in accordance with relevant British and European Standards. In this paper only the resilient modules of the tested materials is reported.

RESILIENT MODULUS OF ROAD BASE MATERIALS

Resilient modulus is a mean of predicting the in-service performance of road base materials in a highway pavement. It is defined as the ratio of deviator stress applied to the pavement layers and the resilient axial deformation recovered after release of the deviator stress. Or more simply, a material's resilient modulus is actually an estimate of its modulus of elasticity (E). While the modulus of elasticity is stress divided by strain for a slowly applied load, resilient modulus is stress divided by strain for rapidly applied loads – like those experienced by pavements [pavement Interactive, 2009]. It is the most important materials characteristic for determining whether the materials can be used for a road base layer in a highway pavement. Resilient modulus testing comprises manufacturing cylinders of the specified mixture, curing them in controlled conditions, and carrying out triaxial tests after an agreed timeframe, depending on whether the early, medium or long term life behaviour is to be determined.

The resilient modulus was determined in accordance with [BS EN 13286-7, 2004], by imposing cyclic stresses on a cylindrical specimen that reproduce the stress range in an unbound pavement layer, and in measuring the axial and radial strains of the specimen induced by this loading. The figure below shows triaxial sample ready for testing.

Figure 2. Triaxial Sample with LVDT's Mounted

Various checks were carried out before the specimen was subjected to a conditioning stage before dynamic loads were applied. The conditioning of each specimen was carried out so as to reduce or eliminate any imperfections in the sample during manufacture and to ensure that the sample was in full contact with the platens. Each test specimen underwent three cycles of testing after conditioning and the specimens were given adequate time to relax between cycles. The resilient modulus was calculated by a software programme connected to the Triaxial Machine which records the stresses and strains exerted on the specimen by the applied loads during the various cycles.

It is common knowledge that the resilient modulus of a material is a function of both confining pressure and deviator stress. The confining pressure and deviator stress for this research were selected based on the work of other researchers, such as, [Gudishala ,2004] who used a deviator stress of 103.35 kPa and a confining pressure of 34.45 kPa based on research carried out by the National Cooperative Highway Research Program (NCHRP). For this research the authors decided to apply a more critical stress scenario on the samples. A deviator stress of 120 kPa and a confining pressure of 35 kPa were chosen as shown in table 1 below which shows the load sequence used for testing the samples.

The reason for taken a value of 120 kPa for the deviator stress is based on the conclusion of a research showing that this is the amount of deviator stress at which an element in the middle of a granular road base/sub-base is experienced [FHWA, 1997]. For this purpose the 9th stage of the loading schedule of the triaxial test (Table 1), which includes the deviator stress of 120 kPa and confining pressure of 35 kPa has been selected.

MATERIALS AND LABORATORY TESTING

With the overall aim of this study being to make the initial results for establishing of the early stage resilient modulus of road base materials containing high level of waste limestone, SS and GBS dusts and to further the understanding of the stress dependent mechanical behaviour of SS, GBS and PFA and lime hydraulically bound base materials, it was considered essential to choose a wide range of road base materials as shown in table 2 below, that would display more clearly the benefits or disbenefits of the high level of waste materials.

Four triaxial samples from each of the mixes shown in table 2 were prepared according to the British Standard: B.S. EN 13286-1:2003 and tested for the evaluation of Resilient Modulus, Mr, using the triaxial facility at Liverpool John Moores University.

Samples have been compacted in layers at their optimum moisture contents (see B.S. EN 13286-1:2003) directly into 150 mm diameter circular moulds with a height of 300mm.

RESULTS AND DISCUSSION

Figure 3 and 4 show the triaxial testing results of the mixes. All the mixes were manufactured at their optimum moisture contents and stored in the laboratory at a temperature of approximately 20C^{o} for 28 days before testing.

In figure 3 and at a deviator stress of 70 kPa and 120kPa, the addition of 10% lime stone dust (all dust used in this research work is made from 0.0-4mm size materials) to the limestone control mix yields improvements in resilient stiffness, Mr, of 8% and 22.4% respectively, whereas adding 20% lime stone dust yield a reduction in the stiffness modulus 37.5 % and 29.3% respectively. Showing that in the opinion of the authors that the increase in the amount of dust in the control mix reduces the density of internal interlocking status of the micro structure of the tested samples.

When 10% Steel Slag, SS, waste dust was added to the control mix and at its optimum moisture contents, its Mr is improved by 6.5% at deviator 70 and it reveals a resilient modulus higher than the limestone control mix + 20% lime stone dust by 75%. At a deviator of 120 its Mr is improved by 6.8% and a resilient modulus higher than the limestone control mix + 20% lime stone dust by 51% at deviator 120 is achieved too .

Table 1. Load Testing Sequence for Triaxial Samples

Sequence No.	Cycles	Confining Pressure (σ_3) kPa	Deviator Stress (σ_d) kPa
0*	10000	70	200
1	100	20	20
2	100	20	35
3	100	20	50
4	100	20	70
5	100	35	35
6	100	35	50
7	100	35	70
8	100	35	90
9	100	35	120
10	100	50	50
11	100	50	70
12	100	50	90
13	100	50	120
14	100	50	160
15	100	70	70
16	100	70	90
17	100	70	120
18	100	70	160
19	100	70	200

20	100	100	90
21	100	100	120
22	100	100	160
23	100	100	200
24	100	100	240
25	100	150	120
26	100	150	160
27	100	150	200
28	100	150	240
29	100	150	260

* Conditioning stage

Table 2: Material Types

Material Type/ Mix No.	Mix descriptions
Mix 1	Stancombe* Type 1 – Control
Mix 2	Stancombe Type 1 + 10% Limestone dust
Mix 3	Stancombe Type 1 + 20% Limestone dust
Mix 4	Stancombe Type1 + 10% Steel Slag dust
Mix 5	Stancombe Type 1 + 20% Steel Slag dust
Mix 6	Stancombe Type 1 + 20% limestone dust + 5% GBS (granulated blastfurnace slag)
Mix 7	Stancombe Type 1 + 20% Limestone dust + 10% GBS
Mix 8	Stancombe Type 1 + 20% Limestone dust + 8% PFA + 2% lime

* Stancombe: a local limestone aggregates used for road base materials

Figure 4 also, shows an outstanding increase in the resilient modulus of the following mixes compared with the limestone control mix;
Limestone + 20% limestone dust + 5% GBS,
Limestone + 20% limestone + 10% GBS

They all achieved more than 215% improvement in their Mr values compared with the mix which contains limestone + 20% limestone dust. A closer look at these mixes suggested that they are concrete-like mixes.

Figure 5, shows the results of mix 8 (Stancombe Type 1 + 20% Limestone dust + 8% PFA + 2% lime) at 3 to 28 days. At a deviator stress of 70 kPa and 120kPa , the figure shows that the addition of 10% PFA and lime to mix 8 yields improvements in resilient stiffness, Mr, of 292% and 192.6% respectively. Whereas the results for the same mix at 3 to 14 days achieve a significant values of approximately 53.0% to 70% of the resilient modulus of the control mix at 28 day. This indicates that the addition of PFA and lime to the control mix +20% lime stone dusts yield an increase in the density status of the microstructure of the mixes and thus increasing the internal interlocking status of the tested road base materials.

At LJMU and incorporation with DTI, Aggregate Quarry Association, WRAP and Tarmac ltd, more work is currently undertaken using XRD, ESM, and other normal concrete testing analysis to investigate the mechanical behaviour of these mixes. The research work was extended to include the use of SS, GBS, processed paper waste, lime and different PFA in road base materials containing different high volume of construction dusts. The PhD student Mr. Behrooz Saghafi who is currently carrying out the research work has shown very interesting and good results explaining the reasons behind the increased of these mixes stiffness modulus and other mechanical properties at different ages. His work will be a subject of another paper to be published in the near future.

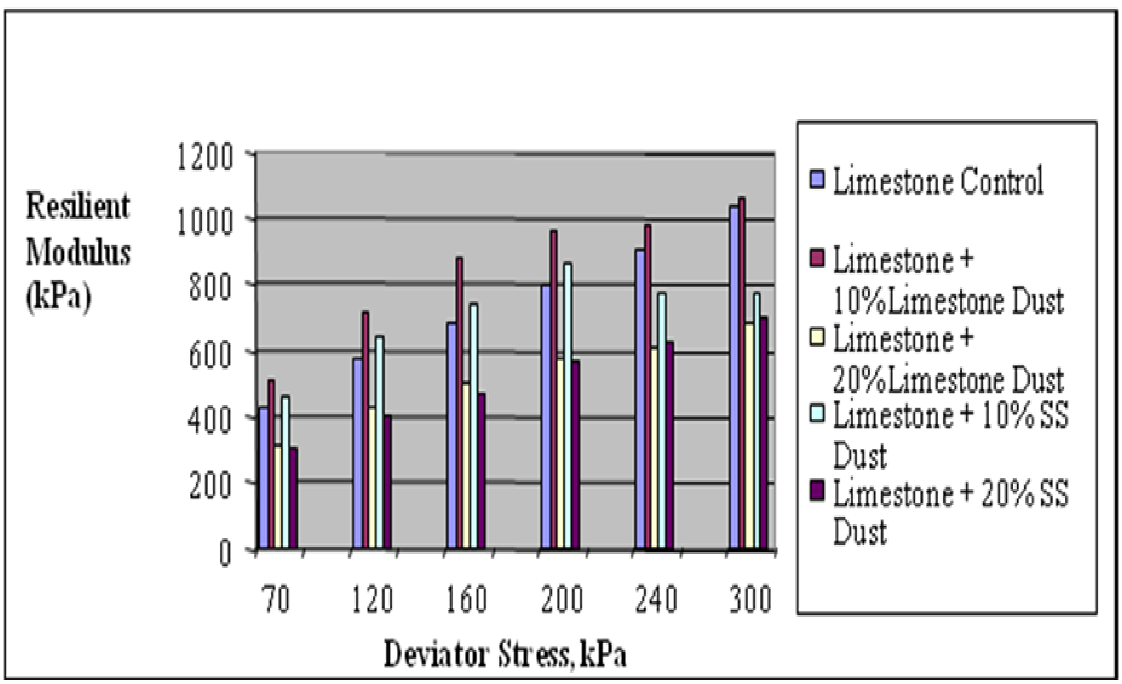

Figure 3. Resilient Modulus (kPa) of Limestone + SS Waste Dust

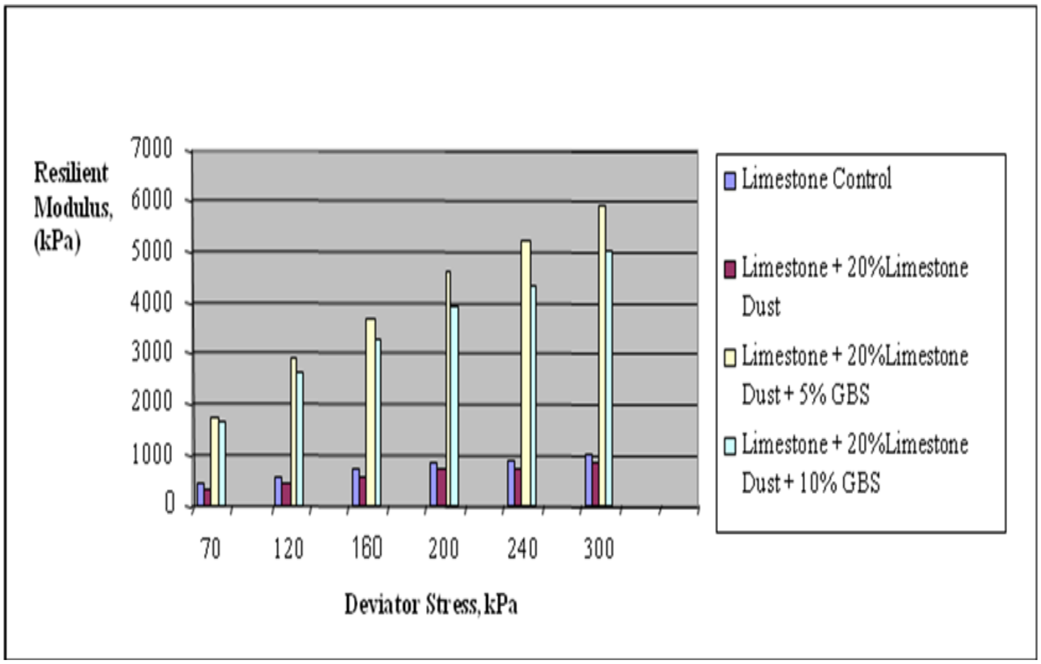

Figure 4. Resilient Modulus (kPa) of Limestoner + GBS Waste Dust

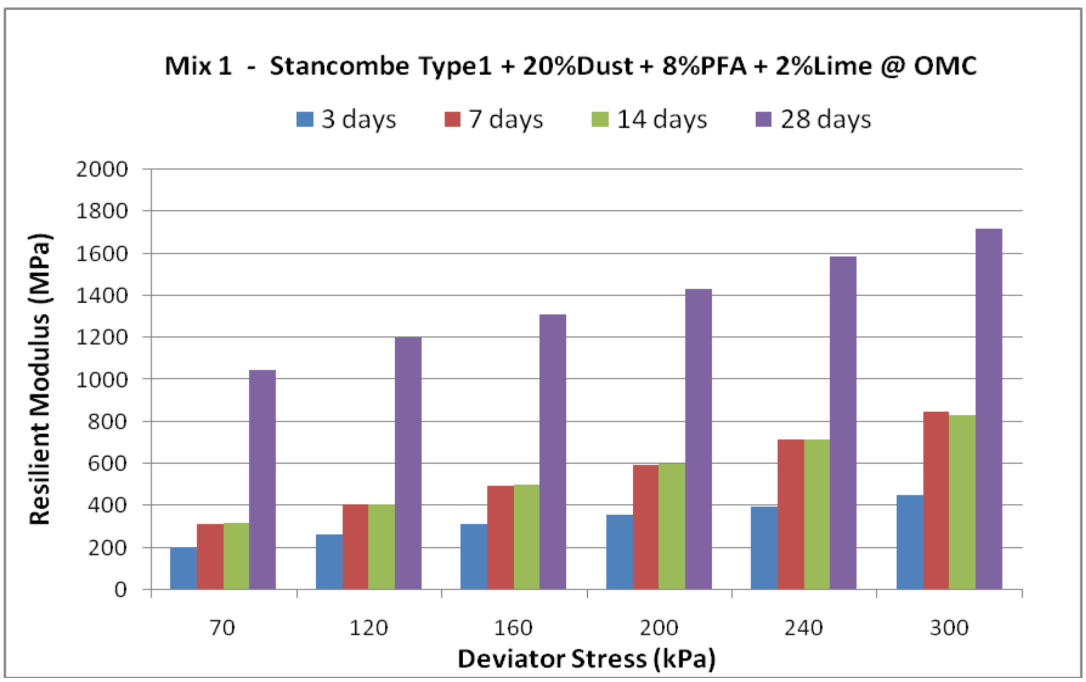

Figure 5. Control Mix + 20% Limestone Dust + 8% PFA + 2% Lime

CONCLUSIONS

1. The addition of limestone dust at a percentage above 10% of the total weight of the road base materials to the lime stone control mix resulted in a substantial reduction in the mix Resilient Modulus, Mr. The reduction in the Mr values is in the opinion of the authors due to the reduction in the state of dense interlocking between the coarse and fine aggregates within the mix. It is commonly known that the increase in the fine material within the compacted road base materials will reduce the optimum interlocking status between the graded aggregate content of the mix and hence the values of the resilient modulus.

2. When steel slag dust added to the control mix at a percentage of 10%, a significant improvement in the values of Mr were achieved showing that the SS dust has reacted with the rest of the fine mix contents and produced higher stiffness. At a percentage level of 20% addition, a significant reduction in the Mr value has been recorded.

3. Mixes contain limestone + limestone dust with added GBS dust, PFA and lime show the highest improvements in the values of Mr. at their optimum moisture contents.
This has led to further research work at LJMU in collaboration with our industrial partners to explain the reasons behind this improvements using conventional concrete testing, chemical testing, XRD and ESM techniques on samples made from different mixes containing different amount of waste dusts (individually and collectively) including different paper processing waste, PFA and lime.

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