# MAKING GOOD USE OF VOLCANIC ASH IN THE PHILIPPINES

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# 1. INTRODUCTION

## 1.1 The eruption of Mount Pinatubo

The eruption of Mt Pinatubo in the Philippines in 1991 resulted in the deposition of some 5-8 billion cubic metres of volcanic ash over the surrounding area. Estimates suggest that this volume only represents 50% of the material produced during the eruption and that over time rains will cause the remaining ash to move down into the lower lying valleys

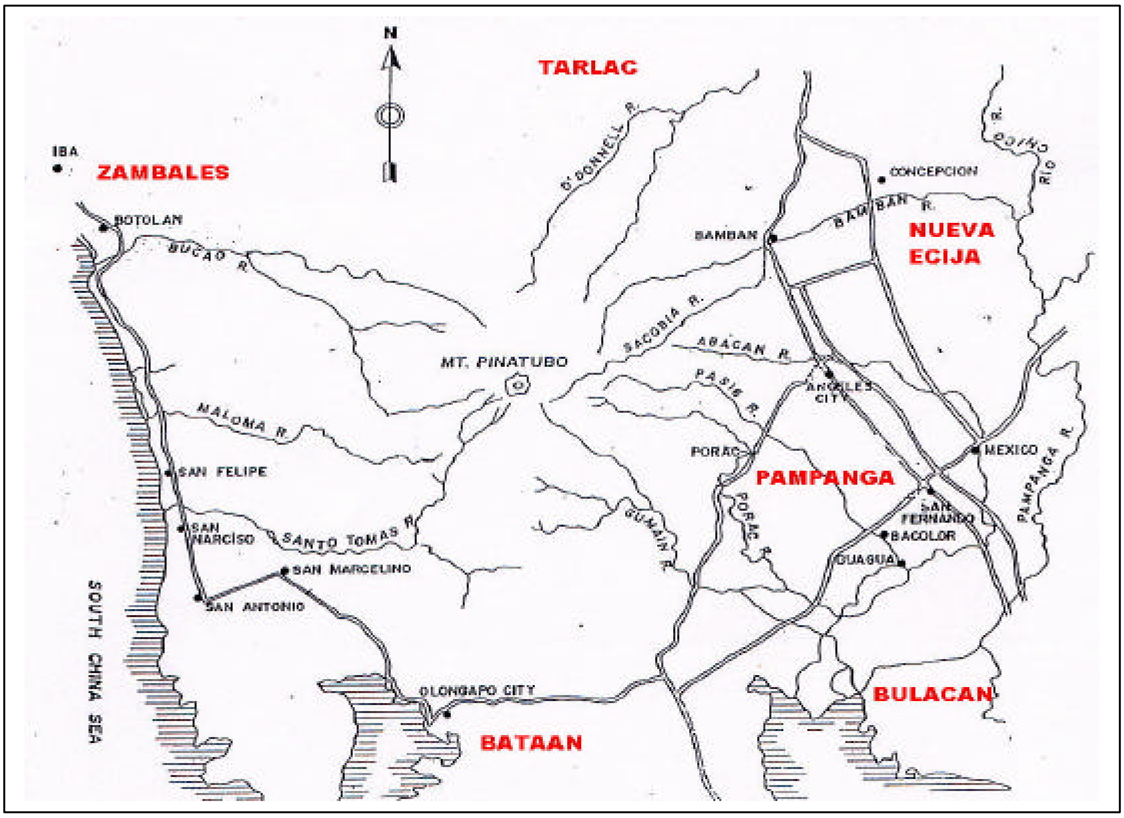


**Figure 1: Mount Pinatubo and the surrounding area**

In response to this catastrophe a large number of organisations have been, and are still, actively involved in research to counteract the economic and environmental impact of the eruption. The majority of the work has been undertaken by Government funded organisations and University departments. Foreign grants, primarily from Japan and the United States, supplemented this work to provide an understanding of the environmental problems of the eruption and the potential for mitigation of the damage. As part of this redevelopment process the Department for International Development (DFID) of the United Kingdom has supported a study of the engineering properties of the ash by the TRL and the Bureau of Research and Standards (BRS) of the Department of Public Works and Highways in the Philippines. The primary objective of the research was to develop standards and specifications for the use of the ash in road construction. As part of this study, the ash has been investigated as roadbase and sub-base type material, as a natural pozzolan and as a fine aggregate in bituminous mixes. This paper discusses the basic physical and engineering properties of the ash, locally known as lahar, and presents the results of a laboratory investigation to determine the performance of Hot Rolled Asphalt (HRA) and Asphalt Concrete (AC) mixes containing lahar.

The results of this and other complementary studies have the potential to significantly reverse the impact of the catastrophe and contribute to an improvement in the livelihoods of the affected population and environment. For example, promoting the use of lahar in road and building construction and in various manufacturing industries increases income earning opportunities for the local population and enables otherwise blighted land to be returned to a productive condition for agricultural purposes. Improvements are also gained in the profile of stream beds and river channels, thus benefiting flood control, irrigation and water quality.

## 2. BACKGROUND

### 2.1 Scale of Problem

Conservative estimates suggest some 5-8 billion cubic metres of pyroclastic material was deposited over the Luzon landscape covering some 400 $km^2$ of land (Newhall and Punongbayan, 1996). In the first five years after the eruption, the lahar flows continued to bring down a staggering amount of additional material that caused the destruction of property and the displacement of some 1.18 million people (Daag and Westen, 1996). Investigations into the scale of the eruption predict that these flows have only removed 50% of the pyroclastic material from the slopes of Mount Pinatubo and that, over the next 50 years, rain water will continue to carry the remaining lahar onto the lower surrounding landscape.

Over the last eight years the newness of the topography and river systems has provided a highly unstable landscape, preventing the early resettlement of once populated areas. Now however, the river system is sufficiently stable to allow some resettlement to occur. This creates a need for buildings and local low volume roads, all of which could, with the right technology, be constructed out of the lahar.

### 2.2 Sources of ash around Mount Pinatubo

Nine years after the eruption, vast areas of fertile farm land and settlement areas have been cleared. The lahar fields that encompassed the land as a result of the eruption in 1991, are largely confined to the river valleys providing ideal quarrying opportunities with fresh material being regularly brought down off the mountain by the rains. Table 1 gives an indication of the volume of lahar in the drainage systems around the Pinatubo volcano.

**Table 1: Data on Pyroclastic Deposits (DPWH, JICA, 1995)**

| Drainage System | Drainage Area (Approx. in $km^2$) | | Estimated Volume of Pyroclastic Deposits (in $km^3$) | | |
|---|---|---|---|---|---|
| O'Donnell | 360 | (San Luis) | 300 | - | 1,000 |
| Sacobia – Bamban | 230 | (Chico R. junction) | 600 | - | 900 |
| Abacan | 80 | (Mexico) | 100 | - | 200 |
| Pasig – Potrero | 110 | (Bacolor) | 300 | - | 500 |
| Porac / Gumain | 310 | (Cabancalan) | 30 | - | 100 |
| Santo Tomas | 310 | (San Felipe) | 1,000 | - | 1,300 |
| Bucao | 660 | (Botolan Br.) | 2,500 | - | 3,100 |
| Total | 2,060 | | 4,800 | - | 7,100 |

## 3. LABORATORY ANALYSIS OF LAHAR

### 3.1 General

Bituminous mixes in the Philippines are currently made with a continuously graded aggregate structure conforming to an Asphalt Concrete (AC) specification (Asphalt Institute 1994). These mixes gain their strength mainly through stone to stone contact within the coarse aggregate structure. On the other hand, gap graded Hot Rolled Asphalt (HRA) mixes (TRL, 1993), which are commonly used in the UK, acquire their strength and stability from the bitumen / filler / fine aggregate mortar in the mix. These mixes have been shown to perform well in the Asian region if properly manufactured, (Dardak et al, 1994 and Dachlan et al, 1997). The coarse aggregate particles in HRA act as an extender but are insufficient to give stone to stone contact. HRA mixes contain a higher proportion of fine aggregate than AC mixes with little material between the 2.36mm and 0.6mm sieves. Typically the fine aggregate in HRA mixes constitutes 40 to 60 percent of mixes made to TRL's Overseas Road Note 31 and UK specifications (BSI, 1992) respectively. Type F mixes in the latter specification comprise natural fine aggregates and processed coarse aggregate.

There would be considerable economic benefit from using lahar in either of these mixes, however, the large percentages of lahar in HRA make this a particularly attractive option. Before introducing a mix specification using lahar it is essential that trials are carried out to evaluate and compare the performance of mixes which utilise the ash.

### 3.2 Materials

The main river systems investigated under this study were the Pasig - Potrero, Bamban - Sacobia and Abacan valleys to the east and the Santo Tomas – Marella river system to the west. Lahar from six different sources were sampled and a programme of laboratory testing initiated to determine the basic physical and engineering properties. Reconnaissance visits were made to other river valleys to ensure the material tested was representative of all the lahar. The following paragraphs discuss the results of the laboratory testing carried out at the BRS and shown in Table 2.

### 3.3 Geological examination

When Mount Pinatubo erupted in 1991 three different mineral fragments were identified within the large volumes of pumiceous pyroclastic flows; mineral crystals (made in the magma prior to the eruption), glass (formed as the magma cooled in the atmosphere) and rock fragments (broken from the crater walls) (Campbell et al, 1982).

A geological examination by the Philippine Institute of Volcanology and Seismology (PhIVolcS) identified the material to be mostly gravel and sand-sized porphyritic, biotite-hornblende, quartz, latite pumice with a few boulder-sized fragments. A subsequent petrographic examination conducted by TRL, in 1999, showed a predominance of plagioclase (35%) and quartz grains (25%) along with agglomerated fine-grained material consisting of the same constituent minerals identified by PhIVolcS. It is likely that the plagioclase fraction was formed during the crystallisation of the hot magma as a result of hot pyroclastic flows being cooled by rainfall and lake breaches.

### 3.4 Grading

The laboratory testing showed a well-graded coarse sand to silt-sized material, classified as a gravelly sand, with typically more than 85% of the material passing the 2.36mm sieve size. The grading suggests that the material would be suitable for mixes made with a ‘gap-graded’ aggregate structure such as HRA, or as part of the fine aggregate component of an AC mix.

### 3.5 Properties of the soil fines

The plasticity characteristics of the soil fines, ie. material less than 0.425 mm sieve, was measured by performing standard Atterberg limit tests and the quantity of fine material was measured by wet sieve analysis. In hot mix asphalt the presence of plastic fines can prevent proper adhesion between the aggregates and bitumen and will lower the quality of the film surrounding the particles. Consequently plastic fines in all hot mixes should be avoided.

With the exception of the Pasig-Potrero II sample, the ash is non-plastic. The Pasig Potrero II sample is representative of the material from the old eruption, which displays some plasticity although its grading characteristics are relatively unchanged. This difference in the plasticity of the new pyroclastic material and material from previous eruptions could suggest that the ash is weathering and breaking down into plastic fines. There is some evidence to support this as local landowners note that during the first few years following the eruption the lahar remained bare. However, it is noticeable that the lahar fields are now covered with tall grass and farmers have commented that whilst the ash was initially deficient in minerals it is now possible to grow some crops.

### 3.6 Specific Gravity

The compositional design of a hot mix surfacing is an essential prerequisite to ensuring that it gives good long-term performance. The balance between the Voids in the Mineral Aggregate (VMA), the bitumen content and the Voids in the Mix (VIM), must be optimised to obtain a strong and long lasting material.

The specific gravity (SG) of the component materials is critical to the proper volumetric design of a hot mix. VMA can be calculated on the basis of the Bulk SG of the combined aggregates in the mix. However, because lahar is porous it is important to take into account the amount of bitumen which will be absorbed into the aggregate particles since this will reduce the effective bitumen content of the mix. To determine VIM, therefore, it is essential to measure the maximum SG ($G_{mm}$) of the mixed materials (ASTM D2041) which allows for the apparent change in SG associated with the absorbed bitumen. Values of Bulk SG and water absorption for the lahar sampled are given in Table 2.

**Table 2: Results of laboratory testing of lahar at BRS**

| Sample No. | 3 | 4a | 4b | 5a | 5b | 6 |
|---|---|---|---|---|---|---|
| **Sample Name** | **Bamban** | **Pasig Potrero I** | **Pasig Potrero II** | **Santo Tomas I** | **Santo Tomas II** | **Santo Tomas D8** |
| **Grading:** | | | | | | |
| **Max. particle size (mm)** | 19.0 | 37.5 | 25.0 | 37.5 | 19.0 | 25.0 |
| **% passing 2.36 mm sieve** | 86 | 64 | 85 | 76 | 85 | 84 |
| **Atterberg limits** | Non-plastic | Non-plastic | LL=24.0-24.5<br>PI = 6-7 | Non-plastic | Non-plastic | Non-plastic |
| **Bulk Specific Gravity** | 2.29 | 2.50-2.55 | 2.55-2.60 | 2.02-2.05 | 2.27 | 2.27 |
| **% absorption** | 4.60 | 2.46 | 3.30-4.17 | 8.22-8.69 | 4.60 | 5.04 |

## 4. PREPARATION OF BITUMINOUS MIXES

The materials used in this laboratory study comprised lahar from a single source river near to Mt. Pinatubo and coarse aggregate and bitumen from the UK. The coarse aggregate was a crushed granite obtained from a quarry in the UK. The fine aggregate was lahar, all passing a 6.3mm sieve, obtained from the Abacan river at San Juan and UK crushed rock fines. A limestone filler was used and the binder was a 60/70 penetration grade bitumen.

### 4.1 Mix design specifications

The AC wearing course grading conformed to the Asphalt Institute (AI) (MS2, 1997) requirements for a mix with a 12.5mm nominal maximum size aggregate. The HRA wearing course grading conforms to Mix WC5 given in Table 8.8 in ORN31 (TRL, 1993). The aggregate particle size distributions for both mixes are shown in Table 3.

The aggregate grading for the AC was designed such that it went above the ‘restricted zone’ developed during the Strategic Highway Research Program (SHRP) and in Figure 2. This helps ensure that the mix has adequate VMA and therefore is more likely to resist plastic deformation under traffic. The aggregate grading for the HRA is shown in Figure 3. The optimum binder content for both mixes was based on the relationship between VIM and the level of compaction using samples compacted in a gyratory compactor.

**Table 3: Aggregate mix proportions**

| Source of material or sieve size on which aggregate is retained | Amount in mix (%) | |
|---|---|---|
| | HRA | AC |
| 14mm | 5 | 5 |
| 10mm | 41 | 30 |
| 6.3mm | 0 | 6 |
| 3.35mm | 0 | 10 |
| Crushed rock fines | 0 | 22 |
| Lahar | 50 | 27 |
| Filler | 4 | 0 |
| Total | 100 | 100 |

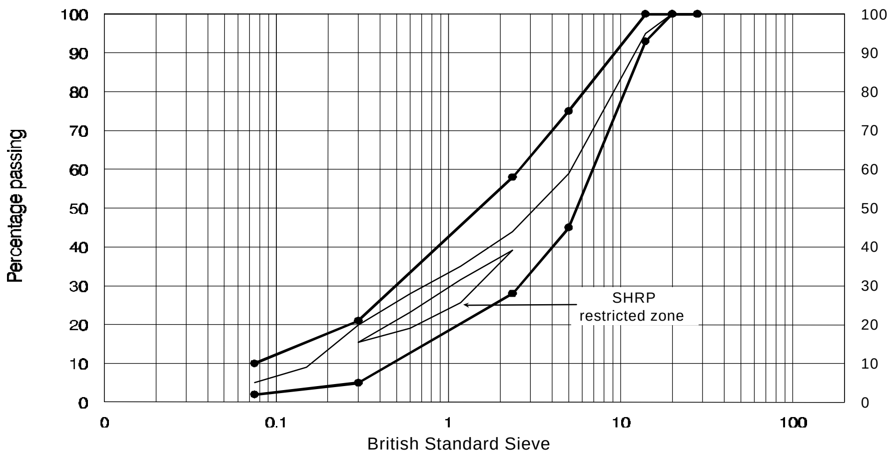


**Figure 2: Grading curve for AC mix**

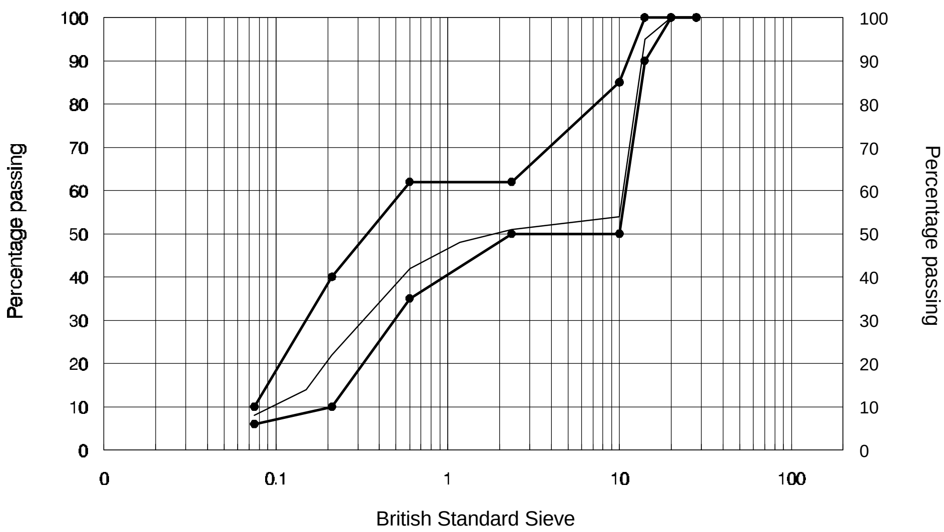


**Figure 3: Grading curve for HRA mix**

## 4.2 Determination of an Optimum Bitumen Content (OBC) for the AC mix

Two sets of samples covering a range of bitumen contents were compacted to refusal density. In this study, this was assumed to be after 600 revolutions in a gyratory compactor. The compacted cores were then tested to determine the bulk specific gravity and maximum specific gravity to enable the relationships between the number of gyrations and VIM to be established. These results are shown in Figure 4.

The SHRP recommendations for a design traffic loading of between 3 and 10 million equivalent standard axles (MESA) and the relationships, shown in Figure 4, suggested that a combination of 120 revolutions in the gyratory compactor and an OBC of about 5.5 percent would produce an acceptable AC mix with 4 percent VIM.

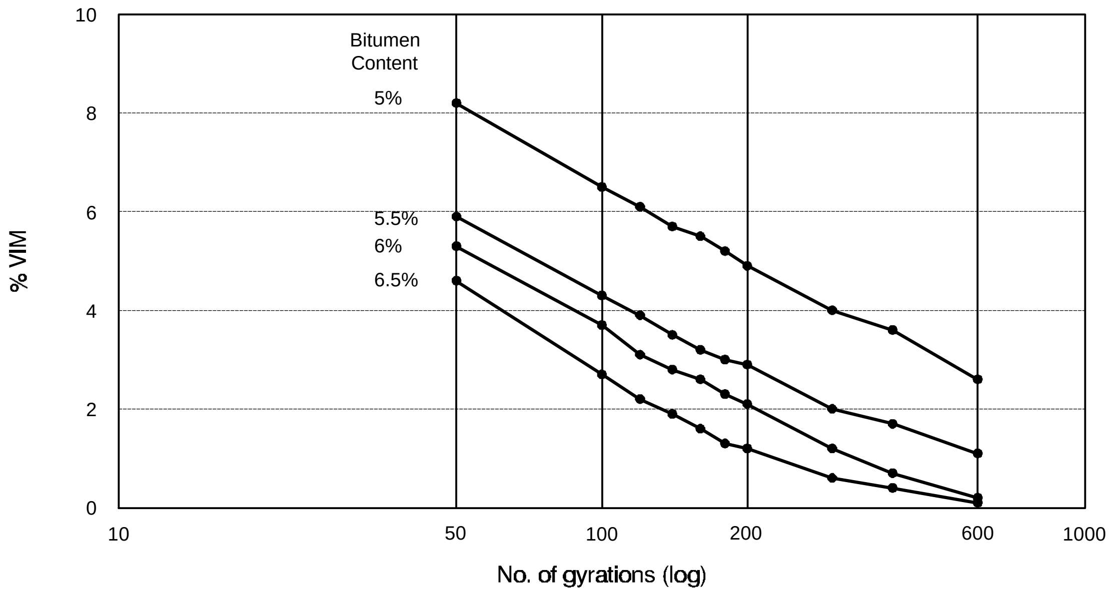


**Figure 4: VIM v Number of gyrations for AC mix**

## 4.3 Determination of an OBC for the HRA mix

An important difference between AC and HRA mixes is the level of VIM at which the two mixes become impermeable. For example, the porosity of AC mixes tends to increase rapidly once VIM values exceed 5 percent, whereas HRA mixes can remain impermeable with VIM values as high as 8 percent. A durable HRA could therefore have VIM of 6 percent. The OBC for the test HRA was selected from the relationships shown in Figure 5 to give a mix which would retain 6 percent VIM at 120 revolutions in the gyratory compactor, i.e. suitable for a design traffic loading of between 3 and 10 MESA. Inspection of Figure 3 shows that the OBC for these conditions is 5.8 percent.

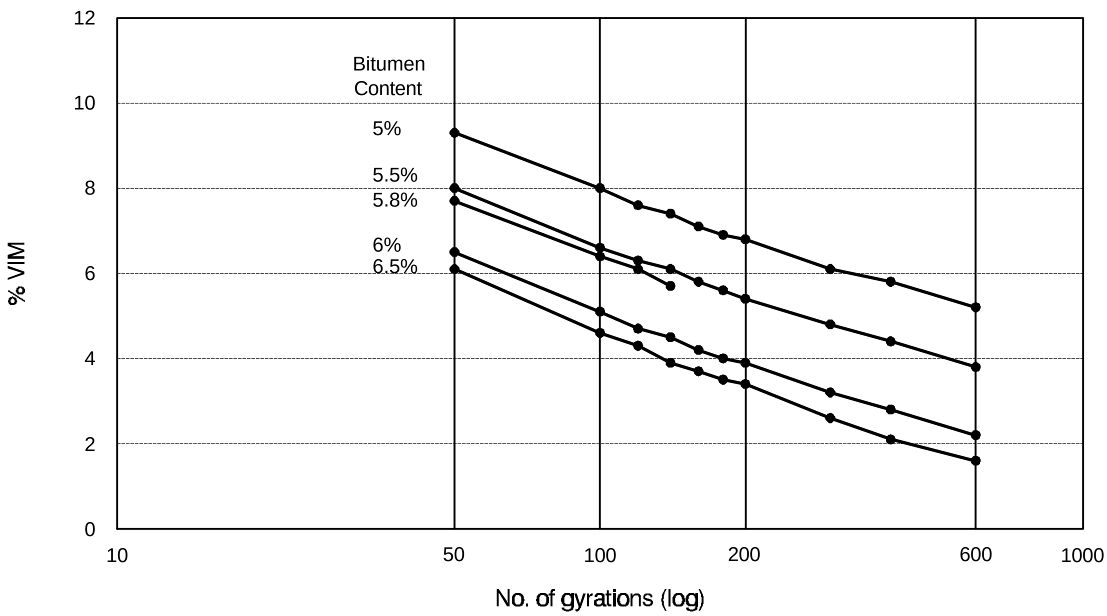


**Figure 5: VIM v Number of gyrations for HRA mix**

## 4.4 Mix performance

Having established the design grading and OBC for the AC and HRA mixes their performance characteristics were evaluated using the wheel-tracking test. This test method is used in the UK to determine the susceptibility of, principally, HRA bituminous wearing course materials to deformation under traffic. The test is carried out at 45°C for sites subject to moderately heavy traffic stresses or 60°C for very heavily stressed sites. A test temperature of 60°C is considered to be appropriate for road surfacing materials to be used in tropical climates and was therefore used in the study.

Mix densification will occur under moderately heavy traffic but it is usually very difficult to predict the rate and degree of secondary compaction that will actually occur. Thus to evaluate the performance of the two mixes, duplicate core samples at three levels of VIM for each mix at the design bitumen content were made in the gyratory compactor.

The composition of the cores used for wheel-tracking tests and the results of the wheel-tracking tests are shown in Table 4. Figure 6 shows the relationship between the mean VIM and mean wheel tracking rates for each mix.

**Table 4: Details of cores for wheel-tracking tests**

| Mix Type | Fine Aggregate | OBC (%) | Core No. | VIM (%) | Tracking rate (mm/hr) | |
|---|---|---|---|---|---|---|
| | | | | | Result | Specification (See note 1) |
| HRA | Lahar | 5.8 | 1 | 7.9 | 0.3 | 5.0 |
| | | | 2 | 7.7 | 0.5 | |
| | | | 3 | 6.1 | 0.2 | |
| | | | 4 | 6.1 | 0.5 | |
| | | | 5 | 4.9 | 0.1 | |
| | | | 6 | 4.9 | 0.0 | |
| AC | Lahar/ Crushed rock | 5.5 | 7 | 7.4 | 0.6 | |
| | | | 8 | 7.6 | 0.6 | |
| | | | 9 | 5.9 | 0.3 | |
| | | | 10 | 5.9 | 0.7 | |
| | | | 11 | 4.7 | 0.4 | |
| | | | 12 | 4.3 | 0.0 | |

Note 1: UK specification for very heavily stressed site.

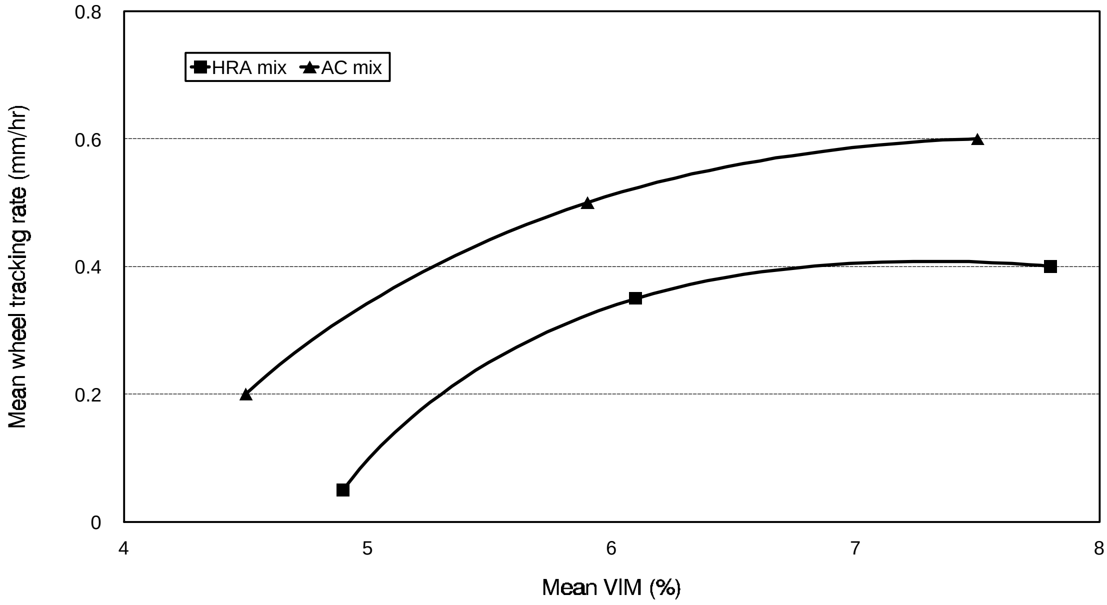


**Figure 6: Relationship between mean VIM and mean wheel tracking rates**

## 5. CONCLUSIONS

The results of the study show that the wheel-tracking rates for both the AC and HRA mixes are similar and compare very favourably with the maximum rate specified for very heavily stressed sites in the UK. Although each of the two mixes are considered to be viable, there would be considerable advantage in using HRA mixes because of the high proportion of selected lahar that can be used in the mix and their generally favourable performance, as shown through studies in neighbouring Indonesia and elsewhere for the reasons given below:

- They are easier to manufacture than AC because fewer sources of aggregate material are required. This means that control of stockpiles is made easier and fewer cold feed bins are needed.
- Mixes of this type are more tolerant of minor errors in composition than are AC mixes.
- They are easy to lay and compact.
- They are impermeable at relatively high VIM values.

Based on these findings a further study is being carried out at BRS using Marshall compaction and a modified version of the BS Refusal Density test (TRL, 1993) to duplicate the results. The findings of the work in the Philippines has continued to demonstrate the suitability of lahar for use in bituminous mixes. Full-scale road trials are now planned and will soon be constructed.

## 6. ACKNOWLEDGEMENTS

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