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MAKING EFFECTIVE USE OF VOLCANIC ASH IN ROAD-BUILDING IN THE PHILIPPINES

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Abstract: The eruption of Mount Pinatubo in the Philippines in 1991 deposited 1.5 billion m^3 of volcanic ash on the surrounding land. The material is accessible and its substitution for other materials ought to provide large cost savings if suitable techniques for using it in civil engineering can be developed. This paper describes the use of the ash as a replacement for conventional fine aggregate in bituminous mixes for road surfacings. A full-scale trial was constructed using hot rolled asphalt and asphalt concrete surfacings containing 53% ash and 17.5% ash respectively. Performance to date has been satisfactory. In the laboratory, performance testing of the trial surfacings using wheel track testing has demonstrated their high resistance to deformation and confirmed the potential suitability of a hot rolled asphalt mix as an effective alternative to the widely-used asphalt concrete. Conclusions are drawn for using volcanic ash in road building.

Key Words: Volcanic ash, Hot mix asphalt, Road surfacings

1. INTRODUCTION

The eruption of Mount Pinatubo in The Philippines in 1991 resulted in large volcanic deposits, locally known as lahar. The material is widely dispersed in three provinces of the Philippines surrounding Mount Pinatubo and is available at low cost. Lahar is presently used in the manufacture of concrete blocks destined for building purposes. It also has the potential for being a source of aggregate used in road construction. The primary objective of this project was to develop standards and specifications for the use of lahar in road construction and consequently achieve a reduction in the cost of bituminous materials.

The grading of lahar from various sources has shown that it could be used as fine aggregate in 'gap-graded' bituminous mixes, such as hot rolled asphalt (HRA), which has been used in the UK as a wearing course for many years.

Hot rolled asphalt acquires its strength from the bitumen/filler/fine aggregate mortar in the mix and therefore contains a high proportion of fine aggregates. This fraction can be as high as seventy per cent of the total aggregate in the mix. These types of mix are therefore ideally suited for incorporating large quantities of lahar. The stages of the project comprised,

1. A review of the location, classification and properties of lahar
2. Laboratory testing of potential sources of lahar for use in road surfacing
3. A preliminary laboratory based study of bituminous mix design using lahar
4. Design, construction and performance monitoring of a full-scale trial
5. Interim assessment of the potential for using lahar and volcanic ash in bituminous mixes for road surfacings.

2. GENERAL PROPERTIES OF LAHAR

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 materials as 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.

Tests on lahar from different sources showed it was a non-plastic, well-graded coarse-sand to silt-sized material with a maximum particle size ranging between 25mm and 37.5mm. Typically, more than 85% of the material passed the 2.36mm sieve size. This suggested that the material would be particularly suitable for bituminous mixes made with a 'gap-graded' aggregate structure such as HRA, or as part of the fine aggregate component of an asphalt concrete (AC) mix. The bulk specific gravity and absorption of the different samples ranged from 2.04 to 2.55 and 2.46% to 8.4%, respectively. This range of porosity, and hence variable levels of absorption of bitumen, needs to be taken into account when calculating the volumetric properties of the bituminous mix.

3. BITUMINOUS ROAD SURFACINGS

3.1 Asphalt Concrete Surfacing

Flexible pavements in the Philippines are almost entirely surfaced with asphalt concrete. Asphalt concrete is a dense mix consisting of continuously graded aggregate and gets its strength from aggregate interlock. Asphalt concrete has a low voids content and consequently a low permeability. The permeability of AC mixes increases rapidly once the air voids exceed 5% and because of the requirement for low air voids they are sensitive to errors in proportioning.

A more tolerant mix can be developed by using gap-graded mixes that have a higher air voids content than AC, but are just as capable of resisting climatic and traffic related damage. One mix of this type is hot rolled asphalt.

3.2 Hot Rolled Asphalt

Hot rolled asphalt was developed in the UK and makes use of sand which is readily available from abundant resources found in sand and gravel pits. Its mix composition is based on a recipe method wherein the grading of the aggregates, bitumen type and quantity are within prescribed limits. It is less dense than AC, containing air voids (voids in mix, VIM) of approximately 8%, but it is impermeable. It retains its impermeability because the air voids tend to remain discontinuous even though the VIM content is higher. Consequently, the mix tolerances for HRA are normally wider than for AC and it is less sensitive to variations in the bitumen content.

The main difference in the grading requirements of an HRA mix as opposed to an AC mix is the introduction of a gap in the grading between the 2.36mm and 9.5mm sieve sizes. Coarse aggregate and filler are added to produce a particle-size distribution parallel to the boundaries of the grading envelope. Hot rolled asphalt gains its strength from the bitumen, filler and fine aggregate mortar. The coarse aggregate particles act as an extender but are insufficient to give stone to stone contact. At high proportions, the coarse aggregate provides an adequate surface texture, the preferred target for coarse aggregate being about 50%.

The specification for HRA indicates a preference for using 40/50 penetration grade bitumen but, in many countries, bitumen with this viscosity can be difficult to obtain. Alternatively, it is possible to use a 60/70 penetration grade bitumen provided that the filler to binder ratio is increased to a value close to 1.0; to increase the stiffness of the mortar.

4. PRELIMINARY LABORATORY STUDY

4.1 Preparation of Bituminous Mixes

Both AC and HRA mixes were designed in the preliminary study. The AC wearing course grading conformed to the Asphalt Institute (Asphalt Institute: MS2, 1997) with a 12.5mm nominal maximum size aggregate. The HRA wearing course grading conformed to Mix WC5 given in Table 8.8 in Overseas Road Note 31 (TRL, 1993). The design bitumen content (DBC) for both mixes was based on the relationship between VIM and the level of compaction, using a gyratory compactor, which is suitable for the passage of 1-3 million equivalent standard axles (Asphalt Institute, 1996). The results were encouraging and suggested that the use of lahar in both HRA and AC bituminous mixes was viable.

5. FULL-SCALE TRIAL

A full-scale trial was constructed in April 2002 on a road with a concrete pavement which was in good condition. In the trial, the performance of the experimental AC and HRA sections are compared with that of a control section using a conventional AC surfacing (Item 310, DPWH, 1995). The thickness of the surfacings was 50mm and each section was approximately 100m long. The design of the three sections is shown below:

1. Standard asphalt concrete (Item 310, Grading B), as a control section
2. Hot rolled asphalt with lahar as fine aggregate
3. Item 310 (A) Grading B with lahar as fine aggregate.

5.1 Aggregates Used for the Surfacings

Aggregates were available from suppliers in single sizes of 3/4 and 3/8 inches, and as a manufactured (crushed rock) sand (S1). A natural sand was supplied from a local mountain source and lime was used for the mineral filler. The lahar was obtained from a material source which was approved, from an environmental perspective, by the Department of the Environment and Natural Resources (DENR). Its natural grading is shown in Table 1. The material was typical of that found at many sources.

Table 1. Natural Grading of Lahar

	Sieve size, mm								
	19.5	12.5	9.5	4.75	2.36	0.6	0.3	0.15	0.075
Percent passing	100	98	96	91	83	52	27	12	3

5.2 Mix Design

The job mix composition for each of the materials used in the trials was determined by the Marshall laboratory method of mix design. The DBC for the control section of conventional AC, the AC Lahar mix and the HRA were found to be 5.5%, 4.9% and 5.8% respectively. The amount of lahar used was 17.5% and 53% of the total aggregates in the AC and HRA respectively. Further details of the proportion of aggregates used in each of the mixes is shown in Table 2 and the Marshall criteria and specifications are given in Table 3.

Table 2 Aggregate Proportions used in the Mixes

Mix design	Crushed 3/4 inch	Crushed 3/8 inch	Crushed S1 sand	Mountain sand	Lahar sand	Lime
AC Control	19	31	28	20	-	2
AC Lahar	40	23	-	17.5	17.5	2
HRA Lahar	43	-	-	-	53	4

Table 3 Marshall Criteria

	AC Control Mix		AC Lahar		HRA Lahar	
	Spec[1]	Value at DBC	Spec[2]	Value at DBC	Spec[3]	Value at DBC
VIM (%)	3-6	3.5	3-5	4.0	-	3.9
VMA (%)	14-20	14.8	>13	16.0	-	16.3
VFB (%)	70-80	77.3	65-75	72.0	-	76.3
Stability (kN)	>5.3	17.3	>8.0	9.2	4-8	9.8
Flow (mm)	2-4	3.2	2-3.5	2.3	<5.0	2.4

Notes (1) DPWH, Republic of Philippines; (2) Asphalt Institute MS-2;
(3) BS 594 Part 1

5.3 Compaction Trial

A compaction trial was carried out to determine the rolling pattern and frequency to use for the experimental materials in the full-scale trial. A view of the HRA compaction trial while under construction is shown in Figure 1.

The AC control mix compaction procedure had already been established by the Contractor. This was 8-10 passes of an 8-tonne steel-wheeled roller (SWR) followed by 15-20 passes of a pneumatic-tyred roller (PTR). For an AC surfacing layer, the Asphalt Institute (AI MS-2) recommend that the air void content (VIM) of the mix immediately after construction should be approximately 8%.

Unlike an AC mix, there are no compaction criteria for a high stone content HRA. The UK Specification for Highway Works (1998) states that rolling shall continue until all roller marks have been removed from the surface. Clearly, this is a visual judgement which will also depend upon the temperature at which the material is compacted. However, it was deemed useful to gain experience in laying and rolling this material in a compaction trial because HRA was new to the Philippines.

A 25m length adjacent to the location for the full-scale trial was allocated for the compaction trials. The right lane was used for the AC mix and the left lane for the HRA mix. Prior to laying, the road surface was tack coated with a slow setting bitumen emulsion applied at 0.4 l/m^2. Conventional equipment was used for all construction activities.

Figure 1 The HRA Compaction Trial

5.3.1 AC Lahar Mix

AC Lahar was mixed at 150-160°C and laid. The section was then divided into three sub-sections on which three levels of compaction were carried out namely 4, 10 and 16 passes using the SWR. Finally the whole section was finished off with 15 passes of the PTR. The rolling temperatures were between 100 and 120°C.

Cores were taken and for each of the sub-sections (4, 10, and 16 passes), the mean VIM content of the cores was found to be 9.1%, 7.4% and 7%, respectively. Thus it was decided that a rolling pattern of 8 passes of the SWR followed by 15 passes of the PTR would be needed to achieve the 8% VIM immediately after construction, as specified by the Asphalt Institute.

5.3.2 HRA Lahar Mix

Twelve tonnes of HRA Lahar material were mixed at 150-160°C and laid. It was found that 15 passes of the SWR were sufficient to free the surface of roller marks. Finally, the whole 25m section was finished off with 20 passes of the PTR. The rolling temperatures were between 105 and 109°C. The results of core testing after lay-down showed that the average VIM was 5.7%. This was satisfactory and the rolling pattern was adopted for the main trial.

Having established the procedure to follow, the full-scale trial was readily completed. Samples of the hot mixed material were taken for grading and bitumen content analysis and cores were extracted to measure the bulk density and thickness of the compacted material. The VIM values for each section were 5.6% for the AC control, 7.1% for the AC Lahar and 6.1% for the HRA Lahar. All tests complied with the Job Mix formulae.

6. IN-SERVICE PERFORMANCE OF TRIAL SURFACINGS

The purpose of the full-scale trial was to assess how the various bituminous mixes perform under service conditions. If the HRA and AC mixes incorporating lahar are to be successful then they must resist deformation under conditions of heavy traffic and high temperatures, and they must not fail for any other unforeseen reasons.

The Annual Average Daily Traffic in both directions is 10,500 which comprises, 88% light vehicles, 1% large buses and 11% heavy vehicles. The volume of light vehicles includes motor tricycles. The cumulative traffic after 2.5 years is 2 million equivalent standard axles (mesa) in one direction.

6.1 Wheel-tracking Tests.

This test method is used in the UK to determine the susceptibility of, principally, HRA bituminous wearing course materials to permanent deformation under traffic. In the test two parameters are measured, namely the wheel tracking rate and the maximum rut depth. The wheel tracking rate is the primary measure of the resistance to permanent deformation and the maximum rut depth is a secondary measure to ensure that the performance of materials is correctly assessed. It is necessary because some mixtures may rut and deform excessively in the early part of the test, but not in the latter part, when the wheel tracking rate is determined. For moderate to heavily stressed sites wheel track testing may be carried out at 45^{o}C while for very heavily stressed sites testing is carried out at 60^{o}C. The test temperature has a significant influence on the wheel tracking rate and use of the higher temperature in UK is a severe test of a mixtures ability to resist deformation (Nicholls, 1998). This test temperature was selected for testing the surfacings in this study not only because of very heavy individual and cumulative axle loads but also because of the much higher operating temperatures of the surfacings in the Philippines compared with those in UK.

After 18 months in service 6 core samples were taken from the wheel tracks of each section of the trial and subjected to wheel-track testing in the UK. The wheel tracking rate and rut depth specifications for very heavily stressed sites and the mean values obtained for each of the sections are given in Table 4. It can be seen that the results compare very favourably with the specifications for very heavily stressed sites and give confidence that the bituminous mixes will be resistant to deformation.

The air voids (VIM) of the cores are also given in Table 4. These show that the voids in the two experimental surfacings have remained the same as those obtained by coring immediately after construction and that those for the control section have reduced from 5.6% to 3.9%, after 18 months in service. The reduction in the air voids in the control section is consistent with expectations from the Marshall design criteria, so again these results show that the bituminous mixes are likely to resist deformation.

Table 4 Results of the Laboratory Wheel-track Testing (mean values)

Material	Specimen Density Mg/m^3	VIM %	Maximum Rut Depth (mm)	Wheel-tracking Rate (mm/hr)
Specification			7 @ 60^{o}C	5 @ 60^{o}C
AC Lahar	2.282	7.2	0.5	0.2
HRA Lahar	2.290	6.0	0.6	0.2
AC control	2.385	3.9	0.6	0.3

6.2 Surface Condition Measurements

Various measurements of surface condition were carried out in the early life of the surfacings. For all the sections, the skid resistance measured by the TRL portable skid resistance meter was between 55 and 65 and the texture depth was between 0.3 and 0.5mm. The lowest values of texture depth (0.3mm) were obtained on the HRA section and are as expected because no chippings were rolled into the surface. Cracking is insignificant to date and there is no deformation. It can be concluded that there is nothing in the data so far that gives cause for concern.

7. INDICATIVE COST BENEFITS

For the haul distances commonly in use, the unit cost of asphalt concrete, Item 310 of the DPWH Standard Specifications, is $65 per metric tonne. Of this, 37% is the cost of the aggregates and the remainder is for bitumen, equipment, labour and overhead. The savings from the use of lahar are 18% and 33% of the cost of aggregates in AC and HRA, respectively which gives corresponding savings in construction unit costs of 7.5% and 13.5%. They equate to savings of $7,250 per kilometer for a surfacing with a thickness of 50mm and a width of 7.0m.

Further savings are accrued because 50% of the cost of the lahar is returned to the DENR. Additional savings may be achieved by reducing the proportion of 3/4 inch aggregate in the mix because the cost of this size is 90% higher than the average cost (pick-up prices) of the other crushed aggregates in the mix. This is permitted in the specification for HRA, and finer gradings can be chosen for the AC mix.

When sufficient performance data is available, the potential for whole life benefits will be also considered because if good performance is sustained, they may contribute considerable additional benefits to those attained from unit construction costs.

8. CONCLUSIONS

1. The design of both the HRA mix and the AC mix using lahar followed standard Marshall methods and the design criteria could be achieved. For the HRA, the method was consistent with the recipe method.
2. In the case of the HRA, all of the sand-sized material was lahar and this provided 53% of the total aggregates. For the AC Lahar mix, 17.5% of sand-sized material was lahar sand and the remaining 17.5% was a natural sand.
3. The full-scale trials have been trafficked for 2.5 years and show no signs of deterioration after exposure to the environment and after carrying a traffic loading of 2 mesa. All the sections are performing similarly.
4. Wheel track testing in the laboratory indicates that the mixes will perform under trafficking of up to 10mesa.
5. The cost savings amount to 7.5% (AC Lahar) and 13.5% (HRA Lahar) of the unit cost of asphalt concrete. These savings are considerable.
6. Further savings are possible by reducing the use of one of the standard aggregates (3/4 inch) which is much more expensive than the others. This is permitted within existing specifications.

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