OPTIMIZING THE USE OF MT. PINATUBO LAHAR SAND FOR CONCRETE PAVING BLOCK PRODUCTION

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ABSTRACT

As a consequence of the eruption of the Mount Pinatubo volcano in June 1991, the Philippines has 11 billion cu. m. of lahar deposited in the central Luzon area. The technology now in use and the rest that are still being developed towards the wise utilization of these materials to date are still insufficient. Much more are desired.
In 1996, an exploratory work on the use of the Mt. Pinatubo lahar sand as the main component in the production of paving blocks was undertaken. Paving blocks were produced using a locally fabricated manual block maker. A test pavement was laid and was subjected to repeated passage of a passenger jeepney loaded with gravel. The blocks in the test pavement were observed to perform well and showed no cracking failure, and was recommended to be suitable for parks and parking area applications. The blocks were produced at an aggregate-cement ratio (mass proportion) of 3.50:1, which is fairly high, making the blocks quite expensive.
This succeeding work is an effort to determine the parameters for the optimal production of paving blocks using lahar sand as the main component by investigating the effects of W/C, A/C and partial replacement of lahar sand by crushed sand. The parameters for evaluation were compressive strength, flexural strength, and abrasion loss by the Cantabrian Los Angeles and rotating-cutter methods. The results are reported in this paper.

1. INTRODUCTION

The Mt. Pinatubo volcano is one of the composite volcanoes known as the Luzon Volcanic Arc and is one of the highest peaks in the west-central Luzon. It is located approximately 100 km northwest of Manila. Its periodic eruption between June 12 and 15 of 1991 is considered as the largest global event in the past fifty years prior to it. The eruption itself and its aftereffects, particularly lahar flows have disrupted the supposedly flourishing socioeconomic environment in Central Luzon. The actual amount of quantifiable damage has now become irrelevant compared to the extent of the social implications of the disaster.

According to reports, a total volume of about 3 billion m^3 of tephra-fall was deposited after the eruption. Later estimates put it at 11 billion m^3. While this volume of unwanted materials practically damaged all sources of livelihood in the Central Luzon area, it could also be the means by which the losses brought by the disaster may be partially regained once a wise utilization of it has been found. This is why during the last decade, government as well as non-government agencies had been looking into all possible areas of massive utilization of

the material. A compendium of the research activities on lahar from 1991 to 1997 [1] showed various possible utilization of lahar not only in civil construction works but in foundry works, material science, ceramics, and textile industry as well.

Initial investigations on the physical and chemical properties of volcanic ash as a construction material [2] showed satisfactory properties both in ASTM and BS specifications. Later works [3] also showed successful utilization in ceramic frits and glazes and also in ceramic wall/floor tiles. Other works investigated applications in lightweight concrete [4], in asphalt concrete [5], as embankment material and also as paving block. Today, lahar is already a common fine aggregate in concrete mixes, and in the manufacture of concrete hollow blocks. In spite of these present uses, and even with the implementation of on-going research works into application, there is still much room left for other utilization.

While most of the countries represented in this conference had been into concrete block paving for over 50 years, the Philippines has yet to see considerable use of concrete block pavers in the roads and streets. In 1996, an exploratory work on the use of the Mt. Pinatubo lahar sand as the main component in the production of paving blocks was undertaken [6]. Blocks 96 mm x 196 mm in plan area with a thickness of 85 mm and a 28-day block compressive strength of 18 N/mm^2 were produced by a manual block maker. A test pavement was laid and was tested by making a passenger jeepney loaded with gravel to pass over the pavement repeatedly. The blocks in the test pavement performed well and showed no cracking failure. Consequently, it was recommended to be suitable for parks and parking area applications.

The blocks were produced at an aggregate-cement ratio of 3.50:1 (mass proportion), which is fairly high. This is due to the limitations of the manual block maker machine and on the properties of lahar sand, particularly its grading . It is a common engineering knowledge that the same block compressive strength can be achieved with higher aggregate-cement ratio by modifying the aggregate grading such that the combination of particle sizes would facilitate better compaction, and consequently, higher compressive strength. This can be achieved by the inclusion of another material, and though this would entail an added cost, the process may possibly be offset by a corresponding reduction in the cement content. This succeeding work is an effort to determine the parameters for the optimal production of paving blocks using lahar sand as the main component by investigating the effects of W/C, A/C and partial replacement of lahar sand by crushed sand. The parameters for evaluation were compressive strength, flexural strength, and abrasion loss by the Cantabrian Los Angeles and rotating-cutter methods. The results are given in this paper.

2. TEST PROGRAM

Based on a worldwide survey on the specifications of concrete paving blocks [7], 12 out of 16 countries are using compressive strength as the production control test, two countries are using the flexural strength and another two are using the splitting strength test. Several among them also have specifications on abrasion resistance, water absorption and frost resistance.

This present work involves the investigation of the properties of concrete paving blocks prepared from several mixtures of lahar sand and crushed sand with varying cement contents

and water-cement ratios. The objective is to establish some principles towards the optimal utilization of lahar in the manufacture of concrete paving blocks. The compressive strength, flexural strength, abrasion by Cantabrian Los Angeles and rotating-cutter methods are employed as the means for evaluating the blocks made from the various mixtures.

2.1 Materials and their Properties

Lahar sand was obtained from Pasig Potrero river channel, one of the major rivers into which lahar flows were deposited. The portion of the sand larger than 4.76 mm was removed to avoid a rough texture on the surface of the finished product. Crushed sand (S1) was obtained from a mountain quarry. The properties of the aggregate materials are shown in the Table 1. Observation of the grading shows lahar sand to be a very fine material with a high absorption rate. Previous reports also show that in passing of time, the specific gravity of lahar sand is gradually increasing while its absorption rate is decreasing.

Table 1 Properties of Lahar Sand and Crushed Sand (S1)

	Lahar Sand	S1
Bulk Gs	2.235	2.649
Absorption, %	5.68	2.48
Grading		
Sieve Opening	Cumulative Percent	
mm	Passing, %	
9.52		100
4.76	100	96.3
2.38	92.6	53.6
1.19	80.2	28
0.59	62.3	14.5
0.297	43.9	7.6
0.074	12.9	1.0

2.2 Mix Design

Table 2 shows the mix design variables adopted to determine the influence of W/C, A/C, and replacement of lahar sand by crushed sand S1 on the behavior of the properties of the concrete paving blocks, and thus to determine the optimum mixture.

Table 2 Mix Components

Mix ID	Aggregate Mass, kg		Cement Mass, kg	Water, li	A/C	W/C	S-1 Replacement %
	Lahar	S-1					
A1	25.0	0	5.00	4.80	5.0	0.96	0
A2	25.0	0	5.00	4.50	5.0	0.90	0
A3	25.0	0	5.00	4.25	5.0	0.85	0
B1	25.0	0	6.25	5.00	4.0	0.80	0
B2	25.0	0	5.625	4.50	4.4	0.80	0
C1	20.0	10.0	5.00	4.0	6.0	0.80	33
C2	20.0	10.0	6.25	4.25	4.8	0.68	33
D1	17.5	7.5	5.00	3.90	5.0	0.78	30
D2	17.5	7.5	6.25	4.18	4.0	0.67	30
E1	15.0	10.0	5.00	3.75	5.0	0.75	40
E2	15.0	10.0	6.25	4.00	4.0	0.64	40

2.3 Preparation of Mixtures

Lahar and crushed sand were dried and all materials were proportioned by weight, according to the above tabulation. The materials were mixed in two batches, using an asphalt mixer with rotating blades. Lahar sand, crushed sand and cement were pre-mixed prior to the gradual addition of water, and mixing was continued until a homogeneous mix was achieved. A homogeneous mix was achieved in less than two minutes.

2.4 Molding of Test Blocks

A bench press machine, used in molding forms in metal casting, was used to compress the blocks. A fabricated mold with hinges on all corners for easy removal of the compacted sample was attached at the lower plate of the bench press, and a matching plunger is attached to the upper plate of the bench press. The test blocks were molded with a static compression pressure of 7.0 kg/cm^2. The pressure was held over the block for 5-7 seconds only and then released. After compaction, the formed block is removed from the mold, laid over a non-absorbent bed and allowed to gain sufficient strength overnight in atmospheric condition. After the overnight drying, the sample is immersed in a water tank for 27 days curing.

2.5 Preparation of Blocks for Testing and Testing Procedures

2.5.1 Compression Test

The blocks were taken out of the curing tank and laid over an absorbent surface. The blocks were tested within one hour. The blocks were compressed on its top and bottom surfaces. Plywood sheaths, 3 mm thick, were placed on the top and bottom of the block. The load pacer of the testing machine is set to 95, with an equivalent applied load rate of 19 Ton/min. Compressive strength is computed based on the chamfered area of 188 mm x 88 mm.

2.5.2 Flexure Test

The blocks were taken out of the curing tank and laid over an absorbent surface. The blocks were tested within one hour. Center point flexure test is employed, although prescribed dimensions in ASTM C 293 were not similar. The apparatus used was fabricated, and the dimensions in the test set-up are shown in Figure 1. The load was applied through a strain-controlled compression machine, with a strain rate of 0.5 mm/min.

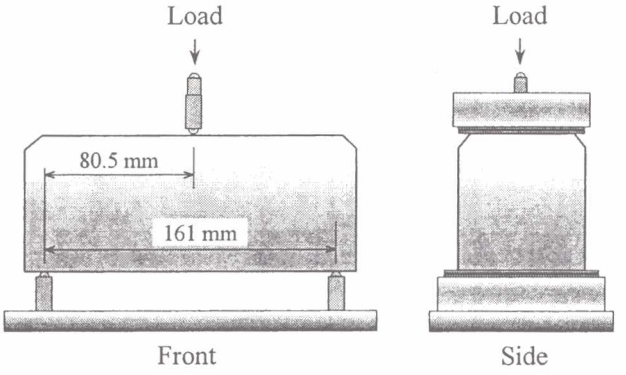


Figure 1 Diagram of Flexure Test

2.5.3 Cantabrian Abrasion Loss Test

The samples used in this test were taken from the flexural strength test samples. One piece was taken from each block tested for flexure. The broken side of the piece was straightened using a concrete slab saw. After cutting, the sample was allowed to dry in the atmosphere for

4 days. The piece is initially weighed, then introduced into the Los Angeles abrasion machine (ASTM C 131), and subjected to 300 revolutions without the balls. The final mass of the abraded sample is measured. The mass difference is expressed as a percentage of the initial mass, and is recorded as its Cantabrian abrasion loss.

2.5.4 Abrasion Resistance by the Rotating-Cutter Method

The samples are drawn out of the curing tank and laid over an absorbent surface and allowed to sufficiently dry in the atmosphere for four days. For this test, three sets were tested: dry, soaked 8 hours, and soaked 24 hours. The dry set was tested after the four day drying. For the soaked sets (8 hr and 24 hr soaking), the samples were soaked for the specified period of time, after which, the samples were laid over an absorbent surface and then tested within 1 hour after removing from the water tank. A drill press similar to that described in ASTM C-944 was adopted in this test, except that the load was applied through the lever. The rotating cutter is fabricated, with an overall diameter on the circular abraded area of 85 mm. Four test periods were adopted: 1 minute, 1 minute, two minutes, and two minutes, in that succeeding order. Mass measurements were taken after each test period.

3. TEST RESULTS AND ANALYSIS

3.1 Effect of Water-Cement Ratio

The effect of water-cement ratio in the hardened properties of concrete blocks were determined by varying the amount of water in the mix of lahar sand with constant cement content by weight of the sand (A/C = 4.0). The lower water content was determined as that which would render sufficient cohesion in the mix after its compression and removal from the mold. It was observed that a very low water content in the mix results to a very smooth block surface but lacks cohesion and chips off at the slightest force. The upper limit of water content was taken as that which would also make the blocks stable after its removal from the mold. Too much water content makes the surface of the blocks very rough, and the blocks are very plastic with the tendency to deform by the pressure of its own weight alone.

3.1.1 Effect of W/C on Compressive and Flexural Strength

The variation of compressive and flexural strengths is shown in Figure 2. The two curves show similar behavior. The block compressive and flexural strength remains the same at W/C from 0.85 to 0.90, but increases to 10% and 20% respectively, at W/C from 0.90 to 0.96. This behavior could mean that at W/C up to 0.90, most of the water is absorbed by the lahar sand and that the remaining water is insufficient for the full hydration of the cement, thus resulting to no increase in the strength of the blocks. However, at W/C greater

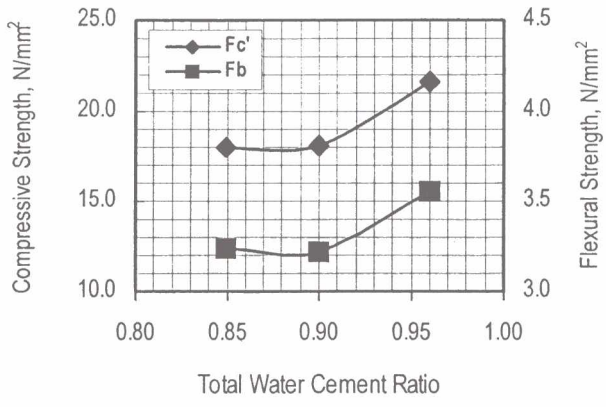


Figure 2 Variation of Compressive and Flexural Strength with W/C

than 0.90, there is sufficient water for the hydration of the cement resulting to an increase in the block compressive and flexural strength. These results imply that in view of achieving the highest strength of the blocks, the maximum W/C ratio should always be used, the limiting value being the plasticity of the mix in order to have sufficient strength immediately after molding.

3.1.2 Effect of W/C on Abrasion Loss

The abrasion test results, Table 3, by the Cantabrian Los Angeles method showed decreasing abrasion loss with increasing W/C. In the rotating cutter method, the test results also showed decrease in the weight loss with increasing water content in all the sample conditions tested. All these imply increased resistance to degradation. For the dry sample, the weight loss data showed a reduction of up to 10 % in the increase of W/C from 0.85 to 0.90, and a reduction of 20 to 32% from W/C ratio of 0.85 to 0.96. Similar observations can be seen in the soaked specimens.

All the test results in strength and resistance to degradation imply an improvement in the hardened properties of the blocks with increasing W/C ratio. As a guide in preparing a design mix for lahar-cement for paving blocks, the highest W/C ratio permissible with the type of machine and method of compaction should be adopted to get the optimum benefits. This observation is consistent with the previous observation with blocks molded using a manual compactor with a much less compacting pressure [6].

Table 3 Abrasion Loss by Cantabrian and Rotating Cutter Method

		Cantabrian Abrasion Loss, %	Rotating-Cutter			
			Weight Loss in Test Period, g			
			1 min	2 min	4 min	6 min
Sample: Dry						
A-3	w/c = 0.85	22.8	7.8	13.2	23.0	33.4
A-2	w/c = 0.90	22.2	7.6	12.6	21.2	30.2
A-1	w/c = 0.96	19.3	6.2	10.2	16.7	22.8
Sample: Soaked 8 hr						
A-3	w/c = 0.85		13.0	22.7	32.1	46.0
A-2	w/c = 0.90		7.2	13.1	22.2	33.5
A-1	w/c = 0.96		4.4	9.7	18.0	25.3
Sample: Soaked 24 hr						
A-3	w/c = 0.85		8.8	14.8	24.2	34.7
A-2	w/c = 0.90		7.4	12.7	21.4	29.6
A-1	w/c = 0.96		6.1	10.8	18.7	26.1

3.2 Effect of Aggregate-Cement Ratio

The effect of aggregate-cement ratio was observed by comparing the block properties of mixes with varying cement content but of equal W/C ratio. Summary of test results is given in Table 4. Values for B1 and B2 show that decreasing the amount of cement in the mix, while maintaining the W/C results to lower compressive and flexural strengths as well as resistance to abrasion. Similarly, a comparison of B1 and A1 also showed reduction of compressive and flexural strengths as well as resistance to abrasion, but to a lesser degree compared to the reduction from B1 to B2, even though the reduction in cement content is more compared to the former. This can only be explained by the difference in the W/C. For A1, W/C=0.96, the maximum for that mix as explained in 3.1. For B2, W/C=0.80 which, based on visual observation of the mix as well as the texture of the compacted blocks is still way below the maximum W/C for such an aggregate-cement ratio.

Table 4 Comparison of Properties with Decreasing Cement in the Mix

		B1	B2	% of B1	A1	% of B1
A/C		4.0	4.4		5.0	
W/C		0.80	0.80		0.96	
Fc', N/mm^2		22.3	175	78	227	97
Fb, N/mm^2		4.35	3.75	86	3.56	82
Cantabrian Loss, %		17.0	19.3	(2.3)	19.3	(2.3)
Mass Loss at 6 min., g	Dry	18.0	23.2	129	22.8	127
	Soaked 8 hr	24.8	33.6	135	25.3	102
	Soaked 24 hr	22.1	33.0	149	26.1	118

( ) Difference with B1

3.3 Effect of Replacement of Lahar Sand by S-1 Aggregate

Figure 3 shows the variation of compressive and flexural strength of blocks with increasing proportion of S1 as replacement of lahar sand. At A/C=4.0, a 25% and 28% increase in the compressive strength with 30 and 40% lahar replacement over the pure lahar-cement mix was observed, respectively. This difference is beyond statistical variations and can be explained as due to the S1 replacement, since all these mixes were prepared with similar A/C and maximum W/C conditions. For the flexural strength, the variations are very minimal. Only slight decreases in abrasion loss

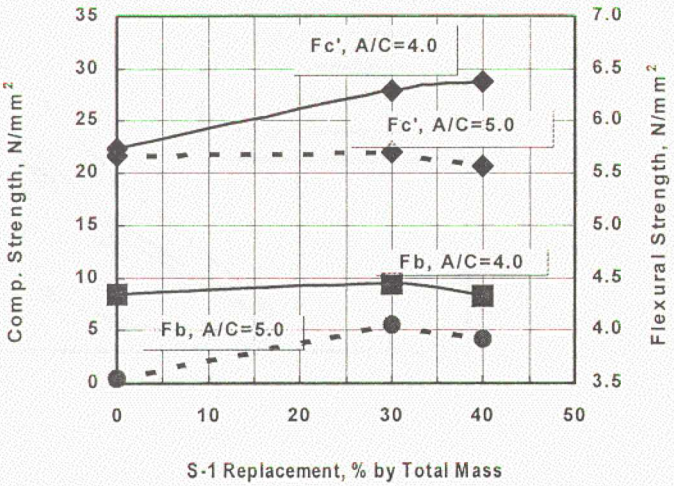


Figure 3 Effect of Replacement of Lahar Sand by S1 to the Compressive and Flexural Srength

were also observed both in the Cantabrian Los Angeles and the rotating cutter methods (see Table 5). At A/C=5.0, there was practically no change in the compressive strength, and only a slight increase in the flexural strength with increasing S1 replacement. The abrasion test results by the Cantabrian Los Angeles method likewise showed negligible change. The abrasion test results by the rotating cutter method were also very small, however, the consistent observation is that there was a reduction in the mass loss with increasing sand replacement.

With the addition of S1 replacing a portion of lahar sand in the mix, the combined aggregate grading is changed (Figure 4). As more S1 is introduced into the mix, the combined grading curve approaches the Fuller maximum density grading curve (n=0.5), and is expected to have a denser packing which would contribute to the strength of the block. Another result of the replacement is the reduction of the total surface area of the combined aggregate, thus making more available cement to coat the surfaces, resulting also to an increase in the block strength.

The reduction in the abrasion loss with increasing amount of S1 is due to the fact that the incorporation of harder materials, i.e., S1, directly resists the abrading action of the dressing wheels. This is consistently observed in all the mixes.

In both the two sets of observations described above, replacement of lahar sand by S1 crushed sand manifests improvement in the properties of the paving block, even up to the 40% replacement level, the maximum level considered in this work. Comparing the results of B1 and D1 both in the flexural and compressive strengths tests, and in the Cantabrian and rotating cutter abrasion loss tests, a reduction in the amount of cement in the mix may be made possible without undue reduction in the properties of the blocks if a portion of lahar sand is replaced with S1 crushed sand. This can be a means of economizing in the material cost of paving blocks.

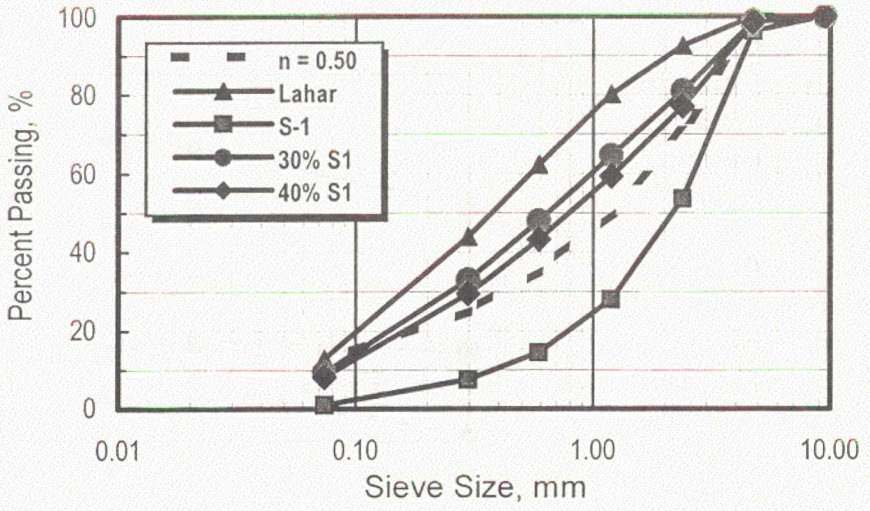


Figure 4 Combined Grading Curves of S1 and Lahar

Table 5 Abrasion Properties with Increasing S1 Replacement

		B1	D2	E2	A1	D1	E1
		A/C = 4.0			A/C = 5.0		
S1 Replacement, %		0	30	40	0	30	40
W/C		0.80	0.67	0.64	0.96	0.78	0.75
Cantabrian Loss, %		17.0	16.6	15.9	19.3	20.0	19.9
Mass Loss at 6 min., g	Dry	18.0	16.4	15.4	22.8	22.7	19.0
	Soaked 8 hr	24.8	18.1	14.9	25.3	20.2	18.8
	Soaked 24 hr	22.1	17.3	12.5	26.1	18.1	18.4

4. CONCLUSIONS

With the limitations of the present work undertaken, the following conclusions can be drawn:

1. To maximize the properties of the blocks, the mixes should be prepared with the maximum water-cement ratio permissible with respect to the machine used in preparing the blocks.
2. Within the aggregate-cement ratio range observed, higher cement in the mix results to improved block properties.
3. The incorporation of S1 as partial replacement of lahar sand in the mix definitely results to higher resistance to abrasion even without an increase in the cement content.
4. Cement content in the mix may be reduced without reduction in the block properties by replacing lahar sand with S1 crushed aggregate.

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