FLEXURAL AND COMPRESSIVE STRENGTH CHARACTERISTICS OF CONCRETE PAVING BLOCKS AND ESTABLISHMENT OF STRENGTH CRITERIA

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ABSTRACT

Concrete paving block in the Philippines is having its beginning in parks and recreational areas, a typical example of which is the EXPO Filipino. In 1996, the Department of Science and Technology funded a small research work on the use of Mount Pinatubo lahar sand in the production of paving blocks, on a small scale using a manually operated single block maker, and testing it for application in parking areas. The field test is now being continued by the Bureau of Research and Standards of the Department of Public Works and Highways. Means of disseminating the technology as a backyard business in the Central Luzon area where lahar sand is abundant is underway, and is expected to gain acceptance in the near future.
When blocks are produced in a small scale, there will be problems in the quality. At present, there is no existing criteria in evaluating the quality of blocks for paving varied types of pavement, e.g. pathways, parking areas, or streets. Block thickness could not be the sole criteria in determining its application, obviously because it does not give any information on its strength. A reliable means of appraising the quality of the blocks to determine its applicability must be established.
In this present work, a laboratory test involving the determination of the compressive and flexural strength of paving blocks prepared from various mixtures of aggregate and cement was undertaken. The plan size of the blocks is 98x198 mm and the thickness is varied at 50, 70, 90 and 110 mm. This paper presents an analysis of the variation of compressive and flexural strength of blocks as influenced by its thickness and proposes a criteria for the strength evaluation of paving blocks for different paving applications.

1. INTRODUCTION

As a consequence of the eruption of the Mount Pinatubo volcano in June 1991, the Philippines has a reported 11 billion m^3 of lahar deposited in the central Luzon area. 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.

One of the potential utilization of lahar sand which can be considered as massive in its scale is in the production of paving blocks. This was initially explored in 1996 [2] where blocks were prepared from a lahar-cement mixture ratio of 3.50:1 (mass proportion) using a locally manufactured manual block maker. The blocks were laid as an initial test pavement and the pavement was subjected to repeated load test using a passenger jeepney loaded with aggregates representing the weight of passengers. Although the compressive strength of the blocks used in the test pavement was only 18 N/mm^2, which is way below the compressive strength criteria of many countries employing paving blocks, it was concluded that such a strength is sufficient for paving not only sidewalks but parking areas as well. Consequently, the utilization of lahar sand for the manufacture of concrete paving blocks was introduced to the Central Luzon area where the lahar material was abundantly deposited.

With the introduction of new materials for any construction application, there should be an accompanying criteria for its quality control. Unfortunately, in the Philippines, paving blocks have already been applied to some projects without the passing of any specification on it. This is perhaps due to the fact that many concrete products companies have made some observations on the neighboring countries and have adopted it into this country, except that their specifications were not implemented.

During the second international conference, a world-wide survey on specifications and standards for concrete paving blocks was presented [3]. In that report, 12 out of the 16 responding countries were using the compressive strength as a production control test, though there were some differences on their specifications on methods and conditions of testing. Also, a notable difference is that while some countries specify a fixed compressive strength regardless of the block thickness, other countries specify strength with variation according to block thickness (Table 1). The countries that recognize thickness as a factor in the strength criteria, Denmark, Italy, Norway and the United Kingdom, specifies in effect a decreasing compressive strength for increasing block thickness, though in different manners. Whether the differences are due to some factors such as the age of the blocks upon testing or were just for simplicity were not indicated in the report.

Table 1 Compressive Strength Specifications with Variation Due to Block Thickness

Country	Specification	
Denmark	Block Thickness, mm	Comp. Strength, N/mm^2
	60	52
	80	49
	100	46
Norway	60	54
	80	51
	100	48

Italy	Comp. Strength (N/mm^2) = K * (Load/Area) where: $K = 50/((13\sqrt{S})/H) + 19.35)$ where: S = plan area (mm^2) H = thickness (mm) Mean Compressive Strength shall not be less than 50 N/mm^2
United Kingdom	Comp. Strength (N/mm^2) = C * (Load/Area) where C: Block thickness (mm) — Plain block — Chamfered block 60 or 65 — 1.00 — 1.06 80 — 1.12 — 1.18 100 — 1.18 — 1.24 Mean Compressive Strength shall not be less than 49 N/mm^2

The absence of a standard specification in the Philippines may be a deterrent to the gaining of popularity of concrete block paving. It may also result to having its applications limited to non-load bearing pavements such as parks and recreational areas only. At this early stage, a method of specifying quality control criteria for paving blocks is necessary.

2. TEST PROGRAM

For concrete products, the most common criteria is compressive strength. In the Philippines, there are compressive strength criteria for concrete and concrete products such as hollow blocks. Flexural strength is also specified when concrete is used in pavement construction. In this work, the variation of flexural and compressive strength of paving block with respect to its thickness were investigated. Different material combinations to prepare the mixtures were adopted.

2.1 Materials

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 2. 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 2 Properties of Lahar Sand and Crushed Sand (S1)

	Lahar Sand	S1
Bulk Gs	2.235	2.649
Absorption, %	5.68	2.48
Unit Weight, kg/m^3	1486	1724
Grading		
Sieve Opening mm	Cumulative Percent Passing, %	
9.52	100	100
4.76	100	96.3
2.38	92.6	53.6
1.19	80.2	28.0
0.59	62.3	14.5
0.297	43.9	7.6
0.074	12.9	1.0

2.2 Mix Design

Table 3 shows the mix design variables adopted to determine the behavior of flexural and compressive strength with respect to block thickness. The higher of the two water cement ratios adopted for the mixes is the maximum level that can be tolerated with the preparation method adopted. The lower ratio is to represent that which may be commonly adopted in the field.

Table 3 Mix Components

Mix ID	Aggregate Volume (0.002 m^3 can)		Cement Mass kg	Water, li	Computed Aggregate Mass kg	Total W/C	Total A/C
	Lahar	S-1					
B1	21	0	12.0	11.5	62.4	0.96	5.20
B2	21	0	12.0	10.5	62.4	0.88	5.20
B3	21	0	15.0	12.5	62.4	0.83	4.16
B4	21	0	15.0	11.5	62.4	0.77	4.16
C1	14	7	12.0	9.5	65.7	0.79	5.48
C2	14	7	12.0	8.5	65.7	0.71	5.48
C3	14	7	15.0	10.5	65.7	0.70	4.38
C4	14	7	15.0	9.5	65.7	0.63	4.38
D1	7	14	12.0	9.0	69.1	0.75	5.76
D2	7	14	12.0	8.0	69.1	0.67	5.76
D3	7	14	15.0	9.5	69.1	0.63	4.61
D4	7	14	15.0	8.5	69.1	0.57	4.61

2.3 Preparation of Mixtures

Lahar and crushed sand were dried and were proportioned by volume using a 0.002 m^3 metal aggregate measure, according to the above tabulation. The materials were mixed using a sand mixer. 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 about 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. For each mix, three blocks for compression and three blocks for flexure tests were prepared for each of the four block thicknesses, i.e., 50, 70, 90 and 110 mm.

2.5 Preparation of Blocks for Testing and Testing Procedures

2.5.1 Compression Test

After 27 days in the water tank, the blocks were taken out and laid over an absorbent surface and 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, which gives 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

After 27 days in the water tank, the blocks were taken out and laid over an absorbent surface and were tested within one hour. Center point flexure test is employed, although prescribed dimensions in ASTM C 293 were not the same. The apparatus used was fabricated, with dimensions in test set-up as shown in Figure 1. The load was applied through a strain-controlled compression machine, with a strain rate of 0.5 mm/min. The flexural strength is computed as

$$Fb = 9.8 * 6\ P\ L/(4\ B\ H^2)$$

where: P = maximum load (kg)
L = Clear distance between supports (161 mm)
B = Block width (98.3 mm)
H = Average block thickness (mm)
Fb = Flexural Strength in N/mm^2

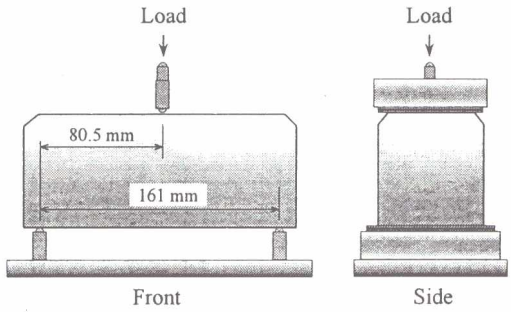

Figure 1 Diagram of Flexure Test

3. TEST RESULTS AND ANALYSIS

3.1 Compression Test Results

Figures 2, 3 and 4 show the compressive strength test results of the various mixes with respect to the block height. All test results show decreasing compressive strength with increasing block thickness. The rate of decrease of compressive strength with respect to block thickness is not constant but rather decreases at higher block thickness, i.e., the relationship shows a power equation rather than linear all throughout the graph.

The compressive strength values of the observed mixes vary widely due to the variation of the composition of the mixes.

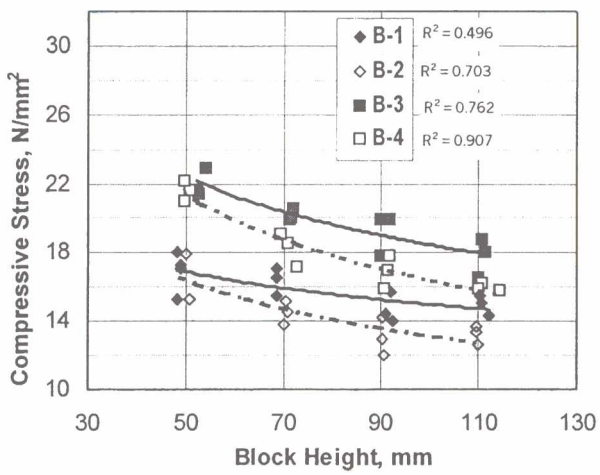

Figure 2 Compressive Strength vs Block Thickness, Mix B

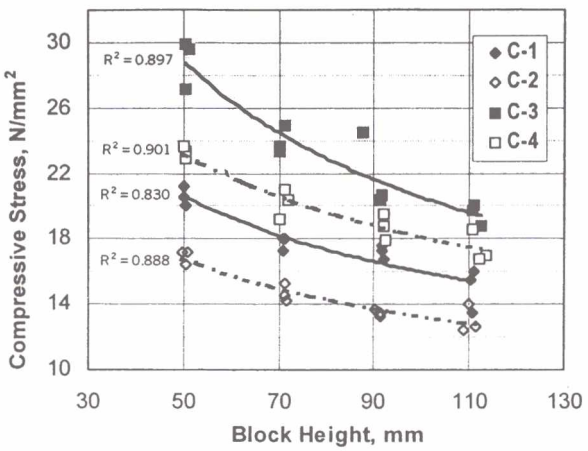

Figure 3 Compressive Strength vs Block Thickness, Mix C

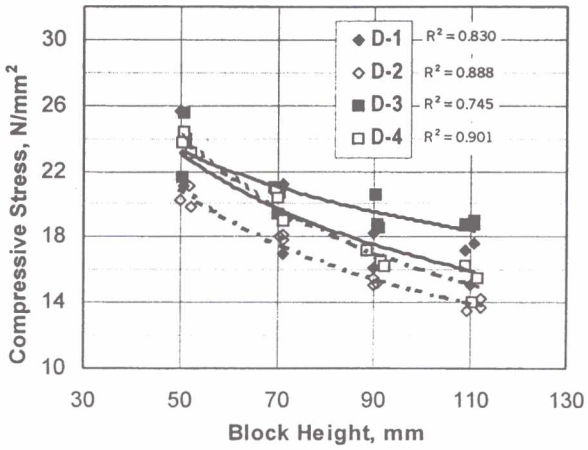

Figure 4 Compressive Strength vs Block Thickness, Mix D

For the purpose of analyzing the behavior of the 12 curves, the relative compressive strength of the other block thicknesses with respect to the compressive strength of 50 mm thick blocks were analyzed. The result of this analysis is shown in Table 3.

Table 3 Relative Block Compressive Strength

	Relative Comp. Strength (% of 50 mm Block Strength)			
Block Thickness,H	50 mm	70 mm	90 mm	110 mm
Mean, %	100	86.8	79.0	74.7
Standard deviation		3.9	5.2	6.5

The results above clearly show the non-linearity of the relationship of block strength with block thickness. The numerical value also shows a significant difference in the compressive strength of blocks prepared from the same mix but with the different thicknesses. Thus, the compressive strength of blocks with different thickness can not be compared. The result signifies sufficient basis for making adjustment in the compressive strength requirement for blocks.

The equation for the above result was determined to be

$$\text{Relative Comp. Strength (\% of 50 mm Block Strength)} = 428.2\ H^{-0.3736} \qquad \text{(Ave. Eqn)}$$

where H = block thickness in mm

For the above equation, $R^2 = 0.9937$. By adopting an arbitrary representative block strength at 50 mm of 28.87 N/mm^2 (Mix C-3), the above relationship is compared with the relationships adopted by other countries as shown in Figure 5. It can be seen that the average equation resembles a similar trend with UK specification, with a slightly lower reduction in strength at higher block thickness. It also shows a lower reduction in strength at higher block thicknesses compared with the rest of the curves, which means that it is slightly more conservative than the rest. Comparing with the results of Mix C-3, the values generated using the equation are

slightly higher than the test results, which means that the average equation is more conservative than the sample test results. Applying the equation into what could be a criteria for compressive strength, the criteria will be as follows:

$$\text{Compressive Strength (N/mm}^2\text{)} = 9.81 * 0.2335\ H^{0.3736} * (P/A)$$

where: H = Block thickness (mm)
P = maximum applied load (kg)
A = net area of block surface excluding chamfers (mm^2)

the compressive strength not being less than a standard (not yet determined for Philippines) depending on what type of pavement the block would be applicable.

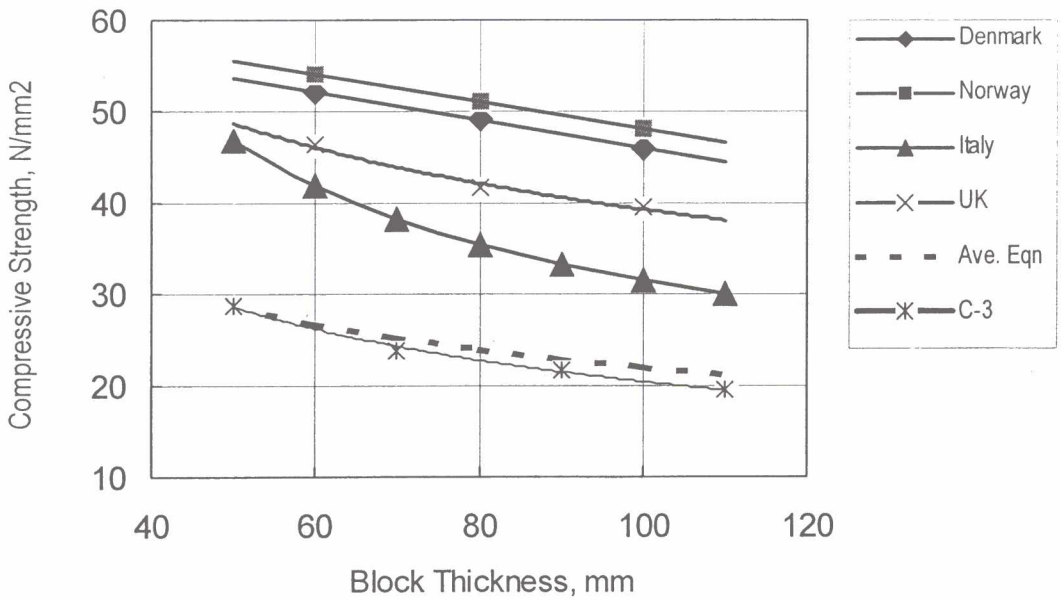

Figure 5 Comparison of Compressive Strength Equations

3.2 Flexural Strength Test

All the countries using the flexural strength requirement specify a single value regardless of block strength. This is obviously because the thickness of the block is incorporated in the calculation of the flexural strength. The flexural strength test results in this work are shown in Figure 6, 7 and 8 for the three sets of mixes. Some of the relationships are linear and some are non-linear. The results were analyzed in the same way as the compressive strength test results and the result is shown in Table 4.

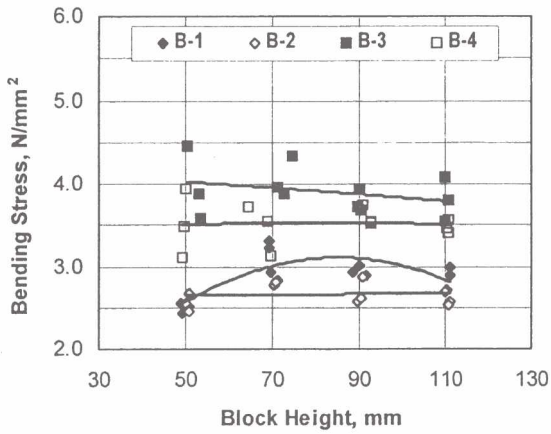

Figure 6 Flexural Strength vs Block Thickness

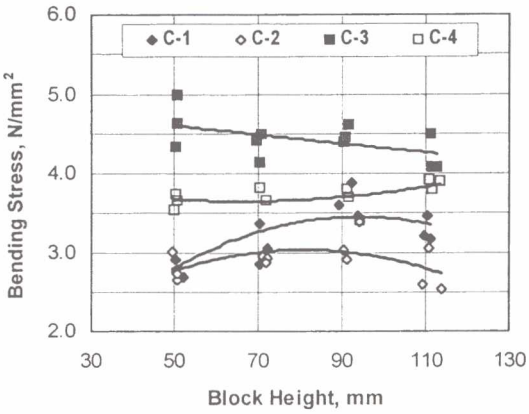

Figure 7 Flexural Strength vs Block Thickness, Mix C

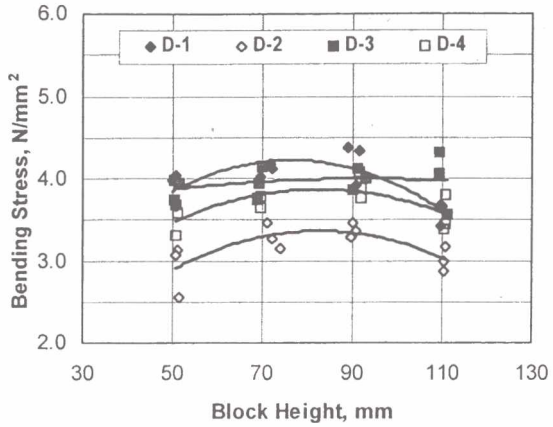

Figure 8 Flexural Strength vs Block Thickness, Mix D

Table 4 Relative Block Flexural Strength

	Relative Strength (% of 50 mm Block Strength)			
Block Thickness, H	50 mm	70 mm	90 mm	110 mm
Thickness-Width Ratio	0.51	0.71	0.92	1.12
Mean, %	100	105.75	107.65	101.48
Standard deviation		7.77	8.69	7.20

The relative block flexural strength at higher thicknesses, expressed as a percentage of the 50 mm block flexural strength were all above 100%. The results also show that block flexural strength increases with thickness up to a point where the thickness-width ratio is approximately equal to 1.0, after which a decrease is seen.

The two countries specifying flexural strength as criteria for blocks, Finland and The Netherlands [3], make no distinction whatsoever in regard to the thickness of the blocks tested. Though the results in this test showed varying block flexural strength at varying block thicknesses, the deviation is not as large as those exhibited in the compressive strength test to necessarily make an adjustment in the flexural strength requirement. Moreover, a specification drawn from results of the performance of blocks with a height-to-width ratio of close to 1.0 will be more conservative when applied to blocks of other height-to-width ratios.

4. CONCLUSIONS

The Philippines at this present time has no specifications yet for quality control of concrete paving blocks. The extent of the work done in this report is not very exhaustive, however the results of the tests may be considered as guidelines in specifying a strength criteria as follows:

(1) For compressive strength criteria, a correction for the compressive strength is suggested as follows:

$$\text{Compressive Strength } (N/mm^2) = 9.81 * 0.2335\ H^{0.3736} * (P/A)$$

where: H = Block thickness (mm)
P = maximum applied load (kg)
A = net area of block surface excluding chamfers (mm^2)

(2) For flexural strength criteria, the minimum value must be based on the flexural strength of blocks with height-to-width ratio of 1.0.

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