STATE OF THE ART OF CONCRETE PAVING BLOCKS IN SRI LANKA (CPBs)

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Abstract: It is in the last five years that the stakeholders of concrete paving blocks (CPBs)areawakening to engineer the CPBs in Sri Lanka. Although large scale production of CPBs has already flourished in Sri Lanka, their adherence with stringent standards (both Sri Lankan and International) remains dubious. This reluctance to meet the performance and durability criteria according to codes of practices, curtails the life span of concrete block paved roads to a greater extent.

The scope of the present paper is limited to verifying whether the local concrete paving blocks are made on par with international standards. Sample blocks were obtained from local CPB manufacturers andinvestigated.Though these blocks met the criteria inSri LankanStandardfor CPBs for strength classes2, 3, 4 roads, none of themmet the compressive strength criteria for strength class 1 roads.

Besides, tensile strength requirement specified in the BS EN 1338: 2003 was met by none of the blocks tested. Since, Sri Lankan Standard is planned to incorporate splitting tensile strength as the dominant measure to assess paving blocks in the near future, this study also attempted to identify a mix proportion to meet the splitting tensile strength requirement specified in BS EN 1338: 2003.

When CPBs were casted using CPB making machine, an intolerable strength deviation was observed. A series of tests were conducted to explore the reasons for this.The outcome of which would help the small scale manufacturers to keep strength variations within a tolerable range, when they are using CPB making machines.

Keywords: Concrete Paving Blocks, Compressive Strength, Splitting Tensile Strength, Strength Deviation, Density

1. Introduction

1.1 The trigger for the use of concrete paving blocks in Sri Lanka

In Sri Lanka, bituminous based products and concrete were used as materials in road construction. However, when there is a need for an excavation such as laying pipe lines to transfer water or laying cables for telecommunication lines, those roads are damaged by the construction firms. In addition, rigid concrete pavements seem to be a failure because of poor quality control during construction and subsequent abrasion damage leaving considerable dust in the air. In addition, frequent repair is required at places like pedestrian crossings, intersections as they are more vulnerable for distresses due to decelerating and accelerating effects of vehicles. Moreover, these rigid concrete pavements are not as economical as either bitumen or concrete block paved roads. The above, trigger the road authorities to go with concrete paving blocks as a demanding alternative paving material.

1.2 State of the art of Concrete paving Blocks in Sri Lanka

Presently, as a successful alternative to the conventional road systems such as bituminous paved roads and rigid concrete pavements, CPBs have been well rooted in Sri Lanka. Thereby large scale production of concrete paving blocks has already been geared up at full pace. However theiradherence with stringent standards (both Sri Lankan and International) remains dubious. Owing to this reluctance to meet the performance and durability criteria,specified in codes of practices, thelife ofconcrete block paved roads has been shrinking. The Figure 1 (TheSunday Times27 November 2011) clearly illustratesthe above loopholes.

Figure 1: Deteriorated Concrete Paving Block found in Kalawila Area

Figure 2:Sample Specimen of Concrete Paving Block made in the laboratory

Moreover, the relaxed approach of the local guidelines to impose stringent guidelines, especially in heavily trafficked highways, coupled with the inadequate facilities available in Sri Lanka to monitor the performance of CPBs tends to curtail the life span of concrete block paved roads. Table 1 [Perera KIJK, 2010) depicts the present state of the facilities available to monitor the performance of CPBs in Sri Lanka.

Splitting Tensile Strength

At the moment only University of Moratuwa is equipped to conduct splitting tensile strength test.

Abrasion Resistance

None of these institutions, as given in Table 1, are equipped to conduct abrasion resistance test. However, a value of 20 mm is given as limiting value to ensure a durable CPB[British Standards Institute 2003, BS EN 1338: 2003].

Slip/ Skid Resistance

Road Development Authority (RDA) Sri Lanka has the facility to measure unpolished slip resistance value (USRV value). By testing several paving blocks (some of them were laid before 17 years) they found that normally concrete paving blocks made in Sri Lanka have USRV more than 45 [Draft Sri Lanka Standard, 'Specifications for Concrete Paving Blocks: Part 1: Requirements'].

Table 1 - Test methods possible in Sri Lanka with various institutions

Organisation	Compression Strength	Tensile splitting Strength	Abrasion Resistance	Slip/ Skid Resistance
University of Moratuwa	√	√	x	x
Road Development Authority	√	x	x	√
National Building Research Organisation	√	x	x	x
Sri Lankan Standards Institute	√	x	x	

1.4 Objectives

In the above background, objectives of the research were set as follows:

- Verify whether the locally made CPBs are on par with the International Standards. (or Sri Lankan Draft Standard)
- Explore the reason for strength deviation observed within the casts (intra casts) and among the casts (inter casts).
- Develop a correlation between density and compressive strength of CPBs.
- Identify a mix proportion to meet the splitting tensile strength requirement specified in BS EN 1338: 2003.

2. Literature Survey

2.1 Characteristics of Concrete Paving Blocks

The working property of paving block concrete is its dry consistency. This allows for direct stripping/demoulding after filling and vibrating the mold. As a result, short processing times of the production process can be realized. A further example of concrete with stiff consistency are roller compacted concrete (RCC) and earth moist concrete [Husken, G &Brouwers, HJH 2008].

2.2 Constituents of Concrete Paving Blocks

Cement, sand and chips are used as basic constituents of CPBs. In addition to the above, pigments are used to colour the CPBs.Moreover CPBs are manufactured from dry consistency mixtures which possess poor flow properties even under vibration. Thus, use of water-reducing or plasticizing admixture to improve compactibilityis a common cost-effective strategy. In addition, admixtures are also assisting CPBs manufactureto reduce cement content and to gain early strength.

Each constituent plays a unique role in CPB when its performance and durability are concerned. Cement acts as a basic binding material in CPB whereas water hydrates the cement and also makes concrete workable. Coarse aggregates act as a basic building component as well as a filler material of concrete while fine aggregates along with cement paste forms mortar grout and fills the voids in the coarse aggregates.

In this respect, ample research works have already been carried out globally to replace the constituents of CPBs [Poon, CS & Chan D, 2007, Gencel, O, Cengiz, O, Fuat, K, Ertugrul E, Gonzalo Martínez-Barrera &Witold, B 2012] as well as in the area of abrasion of CPBs [Horiguchi, T, Kasahara, A, &Ideda S 1994, Dowson, AJ 1996].

2.3 Comparisons and Contrasts of Code of Practices

49 MPa is specified as a minimum compressive strength requirement in BS 6717: Part 1:1993.Whereas thickness and chamfer correction factor (BS 1881: Part 115: 1986) was used to adjust the strength of the test specimen based on thickness. This same criterion is included in the draft Sri Lanka standard for concrete paving blocks 2011 [British Standards Institute 1993, BS 6717: Part 1: 1993, Sri Lanka Standards Institution 2011, 'Specifications for Concrete Paving Blocks: Part 1: Requirements'].

In IS 15658:2006 Indian Standard: Precast Concrete Blocks for Paving - Specifications, different compressive strengths are given to fit with different traffic applications of the roads [Bureau of Indian Standards 2006, IS 15658:2006]. Sri Lankan Draft Standard incorporates the above, but in line with local road conditions.Whereas minimum requirement of compressive strength varies within a range of 15 N/mm^2 to 50 N/mm^2depending on the strength class IV to strength class I [Sri Lanka Standards Institution 2011, 'Specifications for Concrete Paving Blocks: Part 1: Requirements'].

Table 2: Important performance measures specified in codes of practices

Requirement	BS EN1338:2	ASTM C936	Sri Lanka
Compressive strength (MPa)	-	≥ 55.2	Refer Table 3
Tensile splitting strength (MPa)	≥ 3.6	-	-
Skid resistance (BPN)	≥ 45	-	≥ 45
Abrasion resistance	≤23mm	≤15cm^3 /50cm^2	≤23mm
Cold water absorption (%)	-	≤ 5	≤ 6

Table 3 - Different road classes and their corresponding strength, thickness requirements as per Sri Lankan Draft Standard

Strength Class	Average Compressive Strength (N/mm^2)	Individual Compressive Strength (N/mm^2)	Block Thickness (mm)
1 - Class A	50	40	80,100
2 - Class B	40	32	80,100
3 - Class C	30	25	80,100
4 - Foot paths	15	12	60

BS 6717: Part 1:1993 was updated in 2001 which replaced compressive strength by abrasion resistance as a key durability measure. Weathering resistance was also introduced first time as another durability measure, According to draft Sri Lankan standard for concrete paving blocks, compressive strength is the key durability measure which can vary between 15 N/mm² to 50 N/mm²depending on the strength classes. However this is expected to be replaced with the splitting tensile strength in due course [British Standards Institute 2003, BS EN 1338: 2003, British Standards Institute 2001, BS 6717: 2001].

3. Experimentalworks and Observations

3.1 The state of the local Concrete Paving Blocks

3.1.1 Compressive Strength of locally made CPBs

Sample blocks were obtained from local CPB manufacturers and their compressive strengths were measured and tabulated as shown in Table 4.

3.1.2 Splitting Tensile Strength of locally made CPBs

Splitting tensile strengths of CPBs were determined at 28 days. Thicknesses of the specimens were determined from two points before the application of load. The load was applied with a universal testing machine from the middle of the specimen with the apparatus shown in Figure 3.Tensile splitting test results of locally made CPBs are given in Table 5

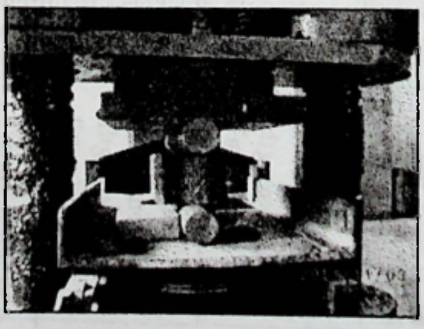

Figure 3: Splitting tensile strength test setup

Table 4: Compressive strength of locally made CPBs

Manufacturer	Sample No.	Dimension (mm)	Compressive Strength (MPa)	Averge Value (MPa)
A	AC-01	220X110X80	41.0	41.98
	AC-02	220X110X80	39.6	
	AC-03	220X110X80	43.5	
	AC-04	220X110X80	41.5	
	AC-05	220X110X80	44.3	
B	BC-01	225X111X80	34.0	42.20
	BC-02	225X111X80	48.0	
	BC-03	225X111X76	46.0	
	BC-04	225X111X80	39.0	
	BC-05	225X111X80	44.0	
C	CC-01	220X110X80	43.0	39.10
	CC-02	220X110X80	39.8	
	CC-03	220X110X80	39.6	
	CC-04	220X110X80	33.9	
	CC-05	220X110X80	39.2	

Table 5: Splitting tensile strength of locally made CPBs

Manufacturer	Sample No.	Dimension	Splitting Tensile Strength (MPa)	Average Value (MPa)
A	AT-01	220X110X80	2.5	2.06
	AT-01	220X110X80	2.2	
	AT-03	220X110X80	1.7	
	AT-04	220X110X80	2.0	
	AT-05	220X110X80	1.9	
B	BT-01	220X110X80	2.7	1.98
	BT-02	220X110X80	2.1	
	BT-03	220X110X80	1.9	
	BT-04	220X110X80	1.5	
	BT-05	220X110X80	1.7	
C	CT-01	220X110X80	2.6	2.08
	CT-02	220X110X80	1.8	
	CT-03	220X110X80	2.1	
	CT-04	220X110X80	1.9	
	CT-05	220X110X80	2.0	

3.2 Selection of Materials

3.2.1 Cement

Ordinary Portland cement made by Tokyo Super has been used throughout the research as a binding material, which belongs to a strength class of 42.5 kN and it is in compliance with SLS 107: Specification for OPC.

3.2.2 Coarse Aggregates

Chips with nominal size of 10 mm are used as coarse aggregates, which is having a specific gravity of 2.73 and dry bulk density of 1456 kg/m^3.

3.2.3 Fine Aggregates

The particle size distribution of the fine aggregates used in the research is as shown in figure 4.

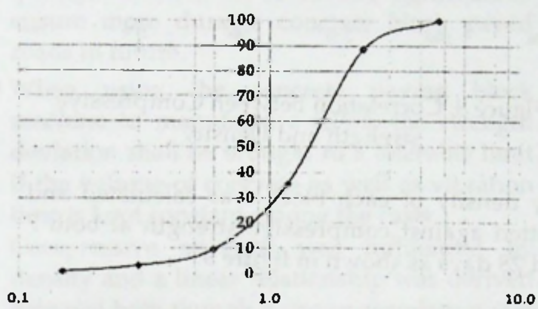

Figure 4: Grading Curve of Fine Aggregates

3.3 Inter cast and Intra cast Variation of Strength

Concrete mix with W / C = 0.35 and A/C = 3.20 was prepared and CPBs were cast in two layers. First layer was laid as shown in figure 5, and compacted using mechanical vibration. Then the second layer was laid and again compacted using mechanically vibration.

Figure 5: After a first layer is laid in the process of CPB making.

The above blocks were cured and tested forcompression on 3,7,14 and 28 days as shown inTable 6. Within the casts (intra cast),compressive strength has standard deviationsof 5.46 N/mm2, 4.92 N/mm2, 8.36 N/mm2, and4.08 N/mm2 on 3, 7, 14 and 28 days.

Table 6: Compressive Strength with in tolerable standard deviation

Sample	Age (days)	Compressive strength (N/mm^2)		Standard Deviation (N/mm^2)
01	3	45.1		
02	3	45.5	42.13	5.46
03	3	35.8		
04	7	40.9		
05	7	43.8	45.00	4.92
06	7	50.5		
07	14	41.6		
08	14	33.3	30.45	8.36
09	14	47.8		
10	14	29.1		
11	28	48.0		
12	28	51.7	52.32	4.08
13	28	51.7		
14	28	57.9		

Another set of experiments were conducted with the intention of reducing the above intolerable compressive strength variation.Throughout this series of tests, volume of concrete as well as the level of compaction was kept same to the extent possible.

Concrete mix was prepared with A/C = 3, but with varying W/C ratio as shown in table 7. Equal amount of concrete waslaid as a first layer and 50 strokes were given using a steel rod shown in figure 6 and then mechanicallyvibrated for about 20 seconds. Then again an equal amount of concrete was used to lay the second layer and the excess concrete was trimmed off to the level. Then 50 blows were given to each block using a steel rod shown in figure 6 and again mechanically vibrated for 40 seconds. These blocks were cured for 28 days and compressive strengths were measured and tabulated as shown in table 7.

Figure 6: The steel rod used for compacting CPB

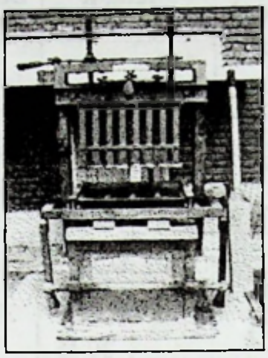

Figure 7: Concrete paving block casting machine

Table 7: Reduced Compressive strength variation after controlling concrete volume and compaction level

W/C	Sample	Age - Days	Compressive strength (N/mm²)		Standard Deviation (N/mm²)
0.300	1_1	28	56.9	52.83	2.77
	1_2	28	50.7		
	1_3	28	51.8		
	1_4	28	51.9		
0.325	1_1	28	53.7	53.00	1.14
	1_2	28	51.3		
	1_3	28	53.6		
	1_4	28	53.4		
0.350	1_1	28	45.4	51.43	4.66
	1_2	28	51.2		
	1_3	28	56.7		
	1_4	28	52.4		
0.375	1_1	28	50.8	50.55	1.17
	1_2	28	49.8		
	1_3	28	52.1		
	1_4	28	49.5		

After controlling the volume of concrete and compaction level, within the casts (intra cast), standard deviations of 2.77 N/mm², 1.14 N/mm², 4.66 N/mm², and 1.17 N/mm² were observed.

3.4 Effect of Density on Compressive Strength

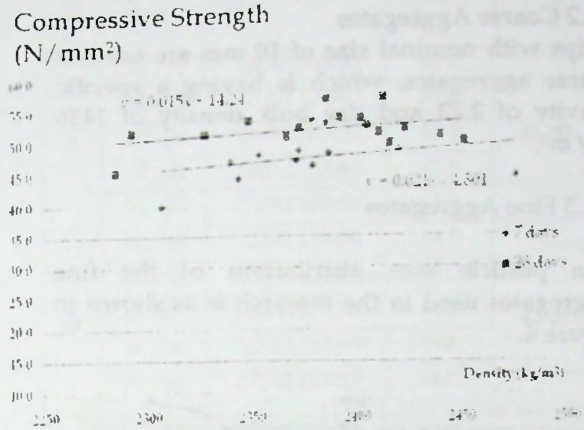

Figure 8: Correlation between Compressive strength and Density

Dry density of each block was calculated and plotted against compressive strength at both 7 and 28 days as shown in figure 9.

3.5 Splitting Tensile Strength

A concrete mix with the proportion of 1 : 0.63: 1.88 : 0.35 cement: sand: chips: water was prepared and cast using concrete paving block machine as shown in figure 7.

At 28 days, these blocks were tested for compression strength as well as splitting tensile strength. An average compressive strength of 59.62 N/mm² and an average splitting tensile strength of 3.68 N/mm² were observed at 28 days.

4. Conclusions and Recommendations

- Though the locally made CPBs tested have met the criterions meant in Sri Lankan Standard for Concrete Paving Blocks for strength classes 2, 3, 4 roads, none of them were compatible with the compressive strength criterion meant for strength class 1 road.
- Moreover, none of these blocks have met the criterion meant in the BS EN 1338: 2003: Concrete Paving Blocks - Requirements and Test Methods for splitting tensile strength. Whereas, Sri Lankan Standard is planned to incorporate splitting tensile strength as the dominant performance measure to access paving blocks in near future.
- In addition, the testing facilities available at various institutions of the country need to be upgraded so that the present mechanisms of quality control shall be further tightened to ensure more durable concrete block paved roads in future.
- When using the concrete paving block machine to manufacture CPBs, the strength deviation shall be brought to a tolerable limit if the volume of concrete as well as vibration time is kept constant among the casts.
- Compressive strength was influenced by density and a linear relationship was derived between both though a strong correlation was not observed.As density influences the compressive strength, the density should be maximized by adequate level of compaction.
- According to BS EN 1338: 2003, minimum tensile strength requirement is 3.6 N/mm^2. Concrete paving bloc
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- ks made with the proportion of 1: 0.63: 1.88: 0.35 cement: sand: chips: water will satisfy the above requirement.

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