New High Strength Water Retaining Interlocking Pavers Block for High Mechanical Performing Pavement and Reducing Runoff

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Abstract. Interlocking paver blocks are used widely at low speed traffic especially within building complexes. Interlocking paver blocks are easy to install and provide aesthetic finishing to the landscape. However, usage of interlocking blocks in large areas reduce ground permeability that lead to higher runoff. New interlocking paver blocks were investigated to reduce runoff and the effect on its mechanical performance. Two types of paver block produced which is paver block with permeable concrete and paver block with void in the center. The results show that the compressive strength for paver block with permeable concrete is averagely higher than paver block with void by 31.5% while the flexural strength of all samples were between 1.0 to 1.7 MPa. Paver block with void recorded highest reduction of runoff compared to paver block with permeable concrete which is 25.5%. This is in line with water infiltration test result. It was concluded that the water retaining performance of paver block increase with increment of void volume and increase in void volume caused reduction on compressive strength of interlocking blocks.

1. Introduction

Interlocking paver block is commonly used as pavement in low speed and low volume traffic especially within building complexes. The main attraction of interlocking paver block would be its aesthetically pleasing colours and shapes besides its ability to bear traffic loading. Many researches have been conducted on increasing the adoption of recycle material in the production of paver block [3] [5] [10] [11] [12] [16]. This would produce a sustainable interlocking paver block. However, usage of interlocking pavement reduce the permeability of ground hence increasing the amount of runoff produced during rain. Few researches conducted on the potential of pavement to serve as drainage layer [6] [8]. This would provide larger drainage system without compromising area for traffic usage. However, the pavement design mostly involves thick pavement system that would be difficult to be implemented on existing pavement system. Hence, a newly designed pavement that could reduce runoff should be almost similar to current design of interlocking paver block which is 200 to 300 mm thickness to ease its adoption. Current research on high performance concrete that could achieve more than 100 MPa compressive strength provide the solution in reducing the thickness of pavement [7] [9].
Pavement with high strength material could perform well in less volume that could be filled with void or porous material in order to reduce runoff. Researches on porous concrete with practical strength would enable the paver block with embedded porous concrete to absorb runoff while minimizing the loss in strength [1] [2] [4] [13] [14]. Hence, this study aimed to investigate the effect of paver block with varied void sizes and block with embedded porous concrete of varied porosity on their compressive capacity, flexural strength and runoff reduction through direct flow and slow infiltration.

2. Materials and methods
2.1 Mix design and Process.
Thirty Six numbers of interlocking paver blocks with dimension of 180 mm (length) x 70 mm (width) x 75 mm (height) were produced with different attributes (Figure 1). Table 1 shows the list of samples produced in triplicate. The mix constituents of base concrete block is as Table 2. The average slump flow measured using slump cone apparatus showed high workability of the mix which is 750mm (Figure 2). This high workability enabled the mix to form around designated spaces for void as per design. For IPB-2%PC, IPB-4%PC and IPB-6%PC; void with dimension of 126 x 50 x 50 mm was prepared from the surface of paver block (Figure 3). This void is to be filled with permeable concrete at later stage. Permeable concrete was made by adding air-entraining agent into high strength concrete to create pores. Mechanical properties concrete with varied air-entraining agent addition is given in Table 3. For IPB-20%V, IPB-40%V and IPB-60%V; paver block is cast until 60mm height with void introduced from surface based on the percentage assigned to each type of sample. Capping was placed prior to second casting of the paver block until full height of 75mm (Figure 1).

| Sample designation | Properties                                      | Numbers |
|--------------------|------------------------------------------------|---------|
| IPB-2%PC           | Contains permeable concrete of 2% air-entraining agent | 6       |
| IPB-4%PC           | Contains permeable concrete of 4% air-entraining agent | 6       |
| IPB-6%PC           | Contains permeable concrete of 6% air-entraining agent | 6       |
| IPB-20%V           | Contains 20% void                               | 6       |
| IPB-40%V           | Contains 40% void                               | 6       |
| IPB-60%V           | Contains 60% void                               | 6       |

| Dry component           | Weight per block (g) | Total 18 nos |
|-------------------------|----------------------|--------------|
| Cement                  | 945.0                | 17.0         |
| Water                   | 189.0                | 3.4          |
| Fine aggregate (600-1180micm) | 945.0 | 17.0 |
| High-range water reducer (HRWR) | 28.4 | 0.5 |

| Percentage by Cement Weight of Air-entraining Agent | Compressive Strength (MPa) | Water Absorption Percentage (%) |
|-----------------------------------------------------|---------------------------|---------------------------------|
| 2%                                                  | 95.4                      | 2.81                            |
| 4%                                                  | 71.3                      | 2.65                            |
| 6%                                                  | 56.8                      | 2.19                            |
2.2 Testing and Analyzing.
All of the samples were tested for runoff reduction followed by water infiltration test and then skid resistance test. Finally, three numbers of samples were tested for flexural strength based on ASTM C 293 and another three samples were tested for compressive strength after 28 days of curing process as per BS EN 1338:2003. The runoff reduction test were conducted using the rate of 200mm/hr to simulate maximum rainfall event. Oven-dried samples were placed in container of 600 x 400 x 300 mm and then sprinkled with water at designated rate. Then the paver block will be weighed to measure the water absorption. Samples were then oven-dried for 24 hours prior to water infiltration test that investigate water ponding effect on test sample. Oven-dried samples were placed in 600 x 400 x 300 mm contained and then submerged in water with 200 mm of excess water depth above the samples’ surface level. Samples were submerged for 15 minutes before taken out for weighing. Skid resistance test was conducted as per ASTM E 303 on all samples after water infiltration test.
3. Results and discussion

3.1 Compressive and Flexural Strength.

Overall, the compressive strength of paver block samples are higher than 40MPa which is the requirement set by BS 6717 [18] (Table 4). Compressive strength of samples IPB-2%PC, IPB-4%PC and IPB-6%PC are higher by at least 92.3% compared to requirement. The highest value was recorded by sample IPB-2%PC which is 108.6 MPa. This may be due to the strength of paver block itself and contribution from permeable concrete that has quite substantial strength. Figure 3 shows that base of paver block cracked while the permeable concrete at the center is still intact which indicate its high strength. For samples with void, the compressive strengths are at least 5% higher than the recommended value. The highest value was recorded by sample IPB-20%V which is 106.5% higher compared to the referred value. In term of flexural strength, all samples recorded values within range of 1.5 to 1.7 MPa except for sample IPB-40%V and IPB-60%V. IPB-40%V and IPB-60%V recorded flexural strength of 1.0 and 1.2 MPa respectively which is quite large reduction compared to other samples. This may be due to void that reduce the volume resisting flexural deformation in the samples. This is congruent with result from sample with permeable concrete (IPB-2%PC – IPB-6%PC) that shows higher compressive and flexural strength due to placement of permeable concrete. The result for flexural strength of all samples are about 15 to 50% lower compared to flexural strength of block pavement with rubber [17].

Table 4. Result of compressive and flexural strength of concrete interlocking block (CIB).

| Type of specimen | Average Compressive Strength at 28 days (MPa) | Average Flexural Strength at 28 days (MPa) |
|------------------|---------------------------------------------|-------------------------------------------|
| IPB-2%PC         | 108.6                                       | 1.5                                       |
| IPB-4%PC         | 87.3                                        | 1.7                                       |
| IPB-6%PC         | 76.9                                        | 1.6                                       |
| IPB-20%V         | 82.6                                        | 1.5                                       |
| IPB-40%V         | 62.5                                        | 1.2                                       |
| IPB-60%V         | 42.1                                        | 1.0                                       |

Figure 3. Compressed samples of (a) IPB-2%PC, (b) IPB-4%PC and (c) IPB-6%PC that show intact permeable concrete.
3.2 Runoff Reduction and Water Infiltration.
Percentage of runoff reduction of interlocking paver block samples show reduction of 6 to 25.5%. Highest runoff reduction by paver block with permeable concrete was recorded by IPB-6%PC with 18.7% (Figure 4). This may be due to the highest amount of air entraining agent in the permeable concrete. However, samples of paver block with void show higher percentage of runoff reduction compared to other samples. Highest percentage was recorded by IPB-60%V with 25.5% while the lowest percentage of 13.5 was recorded by IPB-20%V. This indicates higher efficiency in capturing flowing water in paver block with void compared to permeable concrete. In term of storing water through infiltration, paver block with void recorded highest percentage of water infiltration compared to paver block with permeable concrete (Figure 5). This is shown by sample IPB-60%V with 5.9% of water infiltration. This indicates an efficiency of this type of sample to absorb water using every part of the block as the percentage is the ratio of water absorbed to its dry weight. Paver block with void has lower mass of concrete compared to block with permeable concrete. However, paver block with permeable concrete such as IPB-2%PC only managed to record 1.32% of water absorption and the highest recorded by IPB-6%PC is 3.11%. This shows lower efficiency of these blocks to absorb water. It is worth to note the marginal difference in efficiency of water absorption between paver block with permeable concrete and paver block with void of less than 60. This shows that the paver blocks perform similarly under submerged condition but different in moving water such as runoff. Overall, it can be concluded type of paver block with void is more efficient in reducing runoff and absorbing water as the void is much larger compared to paver block with permeable concrete.

![Figure 4. Result of water absorption.](image-url)
3.3 Skid Resistance.
BPN values for interlocking pavement with permeable concrete is within 34 to 56 which indicates roughness of permeable concrete that are not too varied (Figure 6). For samples of interlocking paver block with void, the BPN values varied from 45 to 78. This large variation is due to inlet holes allocated differently for each type of samples. Samples of IPB-20%V and IPB-40%V have a total of 4 inlet holes. However, distance between holes of IPB-40%V is greater compared to IPB-20%V due to greater dimension of void. For IPB-60%V, 6 inlet holes were provided at greater distance. It can be concluded that increase of inlet holes per area would increase the surface roughness of pavement block with void. It is also noted that inlet holes provide larger friction as indicated by BPN value of pavement block with void as compared to pavement block with permeable concrete. Overall, the BPN value for all samples except IPB-20%PC the safety value of road pavement in the research by Chou & Lee [19] which is 45.

4. Conclusions
Embedment of permeable concrete in interlocking paver block reduce compressive strength of block with increment of perviousness but enable the paver block to reduce runoff with acceptable skid resistance value. Introduction of void within the interlocking paver block greatly reduce runoff and increase skid resistance value while achieving acceptable compressive strength. Hence, development
of paver block with runoff reduction capacity is viable in terms of mechanical performance and resistance for traffic users while having the ability to store water from precipitations. This would reduce the need for open drainages hence maximizing land usage. Future works could investigate the rate of water evaporation of saturated paver block and its long term effectiveness in reducing runoff especially due to clogging in extended usage.

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