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DETERMINATION OF GROOVE AND MECHANICAL PROPERTIES OF UNDERSIDE SHAPED CONCRETE PAVER

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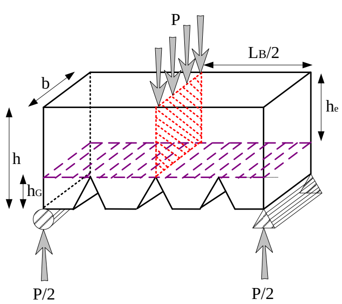
Graphical abstract



Abstract

This paper presents an innovative paver with groove beneath the normal rectangular paver, named as the Underside Shaped Concrete Paver (USCP). A known fact, there is less friction between surface at beneath of paver and bedding sand. Therefore, USCP provide their own grip to bedding sand especially during compaction process. The process of groove determination was first performed before the USCP were tested for compression and flexural strength. The groove was determined based on the theory of bending stress. Combined with several factors, the basic groove shapes chosen were rectangular and triangular. Results indicated that some groove shapes are better in compression, but have weak flexural strength and vice versa. In fact, the relationship between mechanical properties and groove shape is indisputable. It is hoped that the outcomes can be considered in the future to design desirable paver.

Keywords: Concrete paver; underside shaped; groove

1.0 INTRODUCTION

In many countries, concrete paver (CP) have been and are still being used to construct structurally sound pavements for pedestrian and vehicular traffic, even aircraft landing. It is also used extensively in heavy duty industrial paving [1-2]. CP is particularly attractive for surfaces permanently or frequently subjected to high punching shear where conventional pavements may be inadequate. In public precinct and residential neighborhoods, these CP can be pigmented and then laid to any desired pattern to enhance the environmental appeal or even as an aid to local traffic management [3-4].

Almost every country involved in the manufacturing of concrete blocks as pavement materials specifies the compressive strength as the most important property. Generally, compressive strength of concrete block after 28 days of curing must not be less than 49 MPa in accordance to the requirement of British Standard Institution [5] and 30 MPa according to MA 20 [6]. However, according to Shackel [7], average compressive strength of paver is between 25 MPa and 60 MPa.

In a splitting tensile strength test, the material strength of the concrete block is more critically evaluated than its unit strength. BS 6717 [5] specifies the testing procedures to measure the concrete blocks' ability to resist shear force through the tension force generated. However, the accuracy of the test can be affected by the size of aggregate [8]. During the experiment, the surface may break and this allows visual inspection to be done.

The compressive strength and splitting tensile strength of CP material as described above are dependent on the height of the paving units. Generally, the thinner the paving unit, the greater the measured strengths [8]. Flexural (three-point bending) strength, however, is not affected by the thickness of paving units. In here, flexural strength becomes a preferred index of strength. Additionally, it is a more suitable quality indicator.

Most published works have mentioned about normal CP with no groove beneath of paver, which means that our understanding on CP with grooves is limited. This study presents an innovative CP with grooves beneath, i.e., underside, of rectangular blocks named as the 'underside shaped concrete paver' (USCP). This paper intends to discuss the process of groove determination and basic mechanical properties (compression and flexural properties) with the standard requirement of normal CP as it basis. It is hope that, in the future, the findings of this work will assist both researchers and engineers in designing innovative and desirable USCP especially to improve CBP's interlocking mechanism.

2.0 EXPERIMENTAL

2.1 Groove Determination

The USCP in this study was modified from the conventional rectangular concrete block. There were four categories and twelve types of groove shape involved in this study: Trench-3Rectangular Groove (TG-3Rh$_G$), Trench-2Rectangular Groove (TG-2Rh$_G$), Trench-Triangular Groove (TG-Th$_G$), and Shell-Rectangular Groove (Shell-Rh$_G$), as shown in Figure 1.

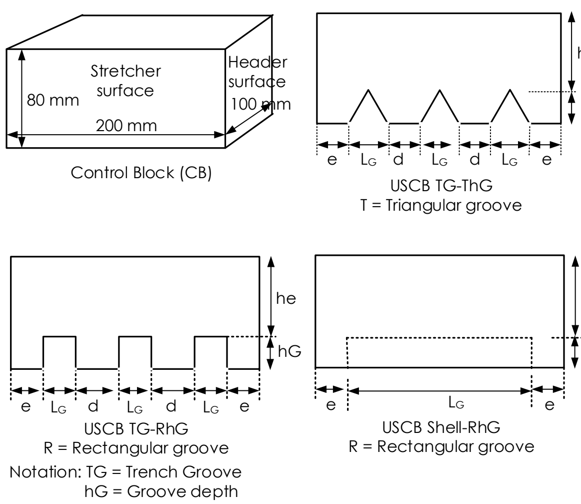


Figure 1 Categories of groove shape

These shapes were chosen since the sand could fill in more easily, as shown in Figure 2. Every USCP had different groove depths, h_G, ranging from 15 mm, 25 mm to 35 mm but excluding the control block (without groove). Shackel [9] mentioned that the bedding sand's thickness normally reduces about 20% to 35% after compaction compared to its original loose thickness. Therefore, it was assumed that some of the sand would fill into the gaps between joints during compaction. Additionally, Lilley [10,11] also stated that blocks laid on loose sand would have its joints filled up 15 mm to 30 mm during compaction.

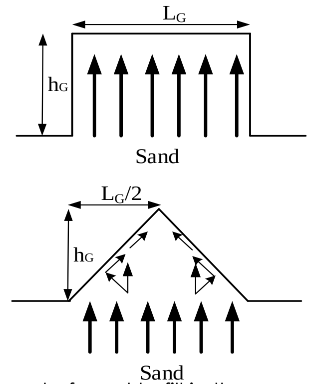


Figure 2 Movement of sand to fill in the groove/shell area

According to BS 6717 [5], the length of the USCP divided by its effective thickness, h_e, should not exceed 5. In this study, the length of the USCP was 200 mm, the minimum effective USCP thickness was 45 mm while the maximum groove depth was 35 mm. Therefore, the length divided by effective thickness would be 4.44, which was below 5. This meant that the maximum groove depth of 35 mm was appropriate. Meanwhile, the minimum overall dimension of web (edge web, *e*, and internal web, *d*) for all shapes was 20 mm. This was specified according to the maximum passing size of coarse aggregate, which was set at 10 mm.

The bending stress of USCP was determined using the elastic flexure formula. Equation 2.1 shows a common formula used to calculate bending stress:

$$\sigma = \frac{My}{I} \tag{2.1}$$

The stresses are proportional to the bending moment, *M*, at the section *y* from the neutral axis, *NA*, and are inversely proportional to the moment of Inertia, *I*, of the cross-section. It is common practice to drop Equation 2.1 since the stress is self explanatory from the bending moment measured [12], since the bending moment is in fact the stresses acting normal to a concrete block. This is shown in Figure 3.

As shown in Figure 3, the bending moment of a concrete block depends on the centre-loading point, *y*, which in turn changes according to the effective depth of the USCP. The value of the moments of inertia, *I*, depends on the shape, width, *b*, and effective depth, h_e, of the concrete block. In the flexure formula, *M*, is measured in Newton-meters, *y* is in meters, *I* is in meters^4, and the bending stress, *σ*, is expressed in Pascals (Pa).

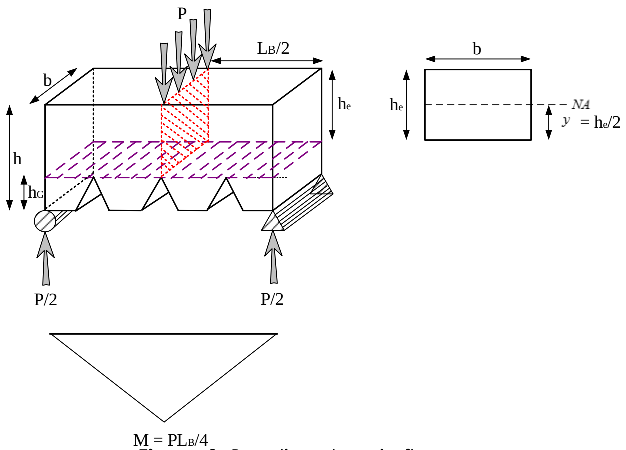


Figure 3 Bending stress in flexure

The groove area was assumed as a load-free boundary of the concrete block since the stress had developed above the dashed line, as shown in Figure 3. A formula of bending stress, σ, for the USCP can be written by combining Equations 2.1- 2.4 into a single equation as shown in Equation 2.5.

$$M = \frac{PL_B}{4} \quad (2.2)$$

$$y = \frac{h_e}{2} \quad (2.3)$$

$$I = \frac{bh_e^{\,3}}{12} \quad (2.4)$$

$$\sigma = \frac{\left(\frac{PL_B}{4}\right)\left(\frac{h_e}{2}\right)}{\frac{bh_e^{\,3}}{12}} = \frac{3}{2}\frac{PL_B}{bh_e^{\,2}} \quad (2.5)$$

However, this formula can only be used for USCP with rectangular and triangular groove shapes. If a USCP has a shell shape, then the shell itself cannot be assumed as load-free because the web of the shell groove, *e*, takes the stresses, as shown in Figure 4.

In this case, Equation 2.1 can still be used to represent such USCP. The differences between this shape and the rectangular and triangular groove shapes are that the centroid lies on the *y* axis and the moment of inertia, *I*, is completely different. The central axis of the areas, $\bar{y}$ and moment of inertial are expressed in Equation 2.6 and Equation 2.7 as follows:

$$\bar{y} = \frac{\sum A_i \bar{y}_i}{\sum A_i} \quad (2.6)$$

$$I_x = \sum\left(\frac{bh^3}{12} + A\bar{y}^2\right) \quad (2.7)$$

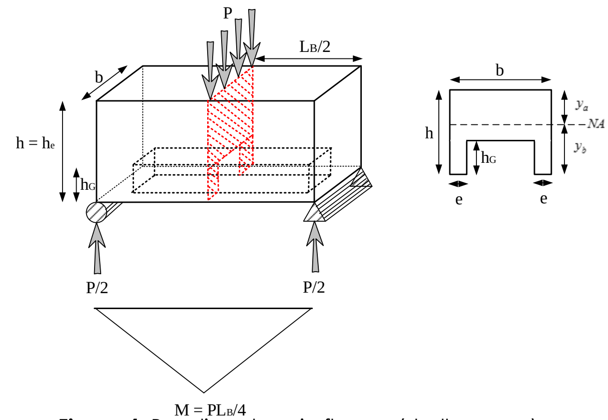


Figure 4 Bending stress in flexure (shell groove)

2.2 Block Manufacturing

A total of 2142 concrete pavers were manufactured. The dry concrete mixtures were prepared according to the requirements of BS 6717 and as recommended by previous research work [13] with zero slumps. The mix proportions used shown in Table 1 as follows:

Table 1 Mix proportion of concrete

Materials	Mix proportion (kg/m³)
Cement content	279
Fine aggregates	728
Coarse aggregates	485
Water cement ratio	0.36

During the process of groove determination, the following shapes of USCP were used:

Shell-R15, 25 and 35	:	Shell rectangular groove with groove depth of 15 mm, 25 mm and 35 mm
TG-T15, 25 and 35	:	Trench triangular groove with groove depth of 15 mm, 25 mm and 35 mm.
TG-2R15, 25 and 35	:	Trench two rectangular grooves with groove depth of 15 mm, 25 mm and 35 mm
TG-3R15, 25 and 35	:	Trench three rectangular grooves with groove depth of 15 mm, 25 mm and 35 mm.

2.3 Compression Test

BS EN 1338 [14], is a standard prepared for precast concrete paving blocks, intended for the construction of low speed roads as well as industrial and other paved surfaces subjected to all categories of static and vehicular loading and pedestrian traffic. In regard to this, the compressive strength of the concrete paving blocks is an important parameter to measure the strength of the blocks. The compression test was conducted by using the TINUS OLSEN Universal Testing Machine with a capacity of 3000 kN and the cross-head speed of the machine was 0.33 mm/min.

2.4 Flexural Test

Flexural strength is a preferred a index of strength and the test method employed in this study followed ASTM C293 [15], using centre-point loading. Since concrete pavement blocks are more likely to break under traffic (fail in bending) than being crushed (fail under compression), it is essential to carry out this test as a more suitable quality indicator. Flexural test subjects a rectangular concrete block pavement to a transverse loading perpendicular to its longitudinal axis and this produces shear and tensile stresses in the concrete block. Similar testing machine and speed rate with compression test were used for flexural test.

3.0 RESULTS AND DISCUSSION

3.1 Effect of Groove Depth on Compressive Strength

Figure 5 illustrates the effect of groove depth on the compressive strength of the concrete block. It seems that deeper groove depth causes lower block compressive strength for all USCP. When the groove depth became deeper, the blocks broke more easily under maximum load because of the stresses developed. Nevertheless, the reduction in the blocks' compressive strength from groove to groove for all USCP was rather small. An exceptional case was found in the shell USCP which had a groove depth of between 25 mm and 35 mm; the reduction in compressive strength was recorded at 23%. In spite of an overall reduction in compressive strength, the TG-T USCP had the highest block compressive strength. All-in-all, most USCP had higher compressive strength than the minimum strength recommended by Shackel [7], except for TG-2R with 35 mm groove depth. Actually, the groove shape also contributed to the block's compressive strength.

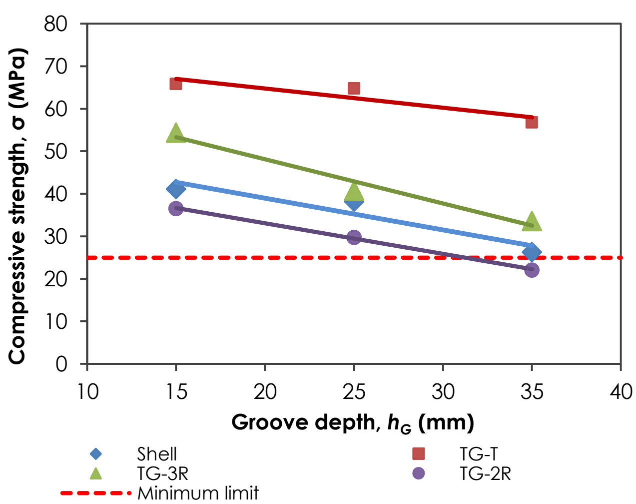


Figure 5 Relationship between compressive strength and USCP groove depth

The effect of groove depth and groove volume on the USCP' compressive strength, as indicated by the results, was highly influenced by the groove shape [16]. TG-T category had the highest compressive strength and this was attributed to the existence of a stiffening web. Generally, the stresses developed are delivered all the way to the groove's web and failure occurs at this weak point. The stiffening web for the TG-T USCP can retain more stresses than rectangular webs.

3.2 Effect of Groove Depth on Flexural Strength

Generally, the value of Modulus of Rupture (MOR) is related to bending stress. The increment in MOR for TG-2R and TG-3R USCP was caused by increased groove depth; the breaking load, *P*; and the block effective thickness, h_e, as shown in Equation 2.5. Higher groove depth means that the block's effective thickness is smaller and this in turn results in higher MOR. Also, higher groove depth also means that the block can bear higher stresses before it fails. The phenomenon can be seen in Figure 6.

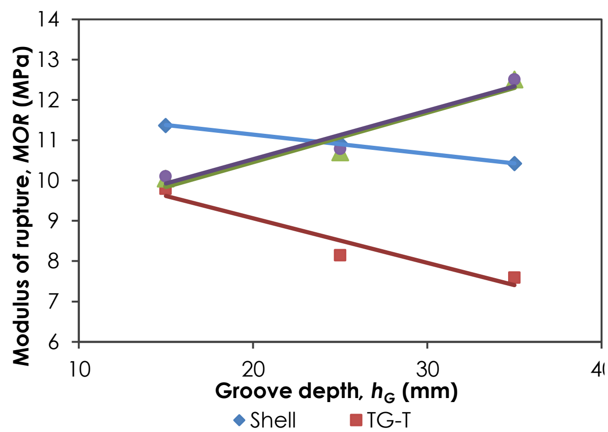


Figure 6 Relationship between MOR and USCP groove depth

On the other hand, decrease in MOR for the shell type is caused by an increment in groove depth. This is because, with deeper groove depth beneath the center of the block, a higher moment will be created during the flexure action and thus increases its probability to fail. A small difference existed in the MOR among the groove depth of 15 mm, 25 mm, and 35 mm, which was up to 8% only. This subtle difference shows that the shell's web had worked to receive stresses during flexure action.

The MOR patterns for the TG-T USCP were noticeably the lowest where its value decreased for 25 mm and 35 mm groove depth for 17% and 7%, respectively. Due to the influence of *P* and h_e, the MOR decreased from 15 mm to 35 mm, but these are not the two major factors that affected the MOR value; it also depends on the failure that has occurred at the triangular notch during the flexure action.

3.3 Relationship of Compressive and Flexural Strength

These USCP have unique mechanical properties and their performances differ from block to block. Nonetheless, the desirable mechanical properties can still be tackled by understanding the relationship between flexural strength, σ_f, and compressive strength, σ_c. In this study, the relationship was prominent because the R^2 for shell and TG-2R USCP was well above 0.9. Meanwhile, the R^2 for TG-3R and TG-T USCP was lower than 0.9 and the TG-T USCP showed moderate relationship (see Figure 7). Among all USCP, only the shell USCP depicted a gradual enhancement in their mechanical properties. The TG-3R and TG-2R USCP, on the other hand, showed a decrement in their flexural strength, σ_f, when their compressive strength, σ_c, decreased. The TG-T USCP had the lowest flexural strength, σ_f. In spite of their inconsistent behaviour, these TG-T USCP still had the highest compressive strength.

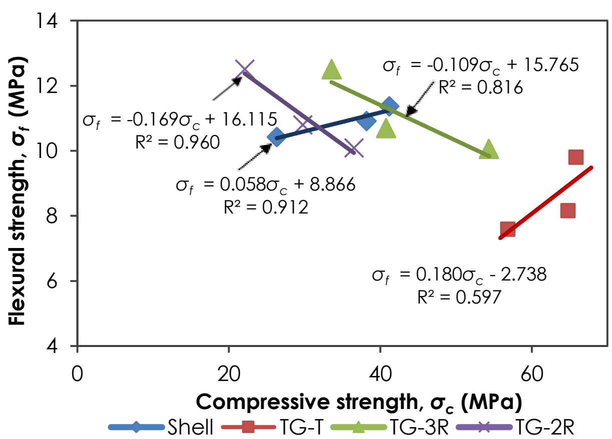


Figure 7 Relationship of flexural strength to compressive strength

4.0 CONCLUSION

From the overall results, it can be concluded that the compressive strength and flexural strength of the USCP depends on groove depth and groove shape. In the design of groove shape, the number and position of notches should be taken into the consideration.

Some shapes are better in compression, but have weak flexural strength and vice versa. In this study, it was found that the TG-T USCP had the best compressive strength while the Shell USCP had the best flexural strength due to their unique web design. However, it can be generally concluded that any triangularly shaped USCP is always strong in compression and any rectangular (TG-2R, TG-3R and Shell) USCP is good in flexure. In addition, only the shell USCP has strong correlation between compressive strength and flexural strength. In this case, the higher the compressive strength, the higher the flexural strength.

Acknowledgement

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